DTIC FILE COPY

2

AD-A226 161

# NAVAL POSTGRADUATE SCHOOL

## Monterey, California

# THESIS

ANALYSIS OF END-TO-END PERFORMANCE
OF LAN SYSTEMS

by

Chou, Chih-Lun

March, 1990

Thesis Advisor: Myung W. Suh

Approved for public release; distribution is unlimited.

Unclassified

Security Classification of this page

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a Report Security Classification UNCLASSIFIED | 1b Restrictive Markings |
| 2a Security Classification Authority | 3 Distribution Availability of Report |
| 2b Declassification/Downgrading Schedule | Approved for public release; distribution is unlimited. |
| 4 Performing Organization Report Number(s) | 5 Monitoring Organization Report Number(s) |
| 6a Name of Performing Organization<br>Naval Postgraduate School<br>6b Office Symbol (*If Applicable*) 32 | 7a Name of Monitoring Organization<br>Naval Postgraduate School |
| 6c Address (*city, state, and ZIP code*)<br>Monterey, CA 93943-5000 | 7b Address (*city, state, and ZIP code*)<br>Monterey, CA 93943-5000 |
| 8a Name of Funding/Sponsoring Organization<br>8b Office Symbol (*If Applicable*) | 9 Procurement Instrument Identification Number |
| 8c Address (*city, state, and ZIP code*) | 10 Source of Funding Numbers |

| Program Element Number | Project No | Task No | Work Unit Accession No |
|---|---|---|---|
| | | | |
| | | | |

11 Title (*Include Security Classification*) ANALYSIS OF END-TO-END PERFORMANCE OF LAN SYSTEMS

12 Personal Author(s) Chou, Chih-Lun

| 13a Type of Report | 13b Time Covered | 14 Date of Report (*year, month,day*) | 15 Page Count |
|---|---|---|---|
| Master's Thesis | From To | 1990, March | 150 |

16 Supplementary Notation The views expressed in this paper are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

| 17 Cosati Codes | | | 18 Subject Terms (*continue on reverse if necessary and identify by block number*) |
|---|---|---|---|
| Field | Group | Subgroup | Local Area Network, LAN, Performance analysis |
| | | | |

19 Abstract (*continue on reverse if necessary and identify by block number*


LAN performance analysis is the main objective of this research. LANs can be configured in various ways. The physical layer combining different medium access control mechanisms and different physical layer specifications divided LLC and MAC. Details on these alternatives are specified in IEEE 802.3 and IEEE 802.5. The queueing network model is one of the analysis tools to investigate the performance characteristics of various LAN configurations. The analysis requires some knowledge of the hardware, software, workload and monitoring tools associated with the system. The queueing network models may be single class or multiple class, and the network of queues may be open system or closed system. Simulation is the approach used to evaluate the actual environment. SIMLAN II will be the simulation tool for our work. Our specification of simulation models involves three classes of transactions, and one or two servers. The input and output of multiple class models are used for three classes of transactions. The network of queues is applied in the closed system. There are 24 simulation results for thesis research. We show the results with respect to LAN utilization, request delay, complete transfer, delivery time, and incomplete transfer. These results, which are arranged in tables and figures, help compare the performance characteristics of various LAN configurations.


| | | |
|---|---|---|
| 20 Distribution/Availability of Abstract<br>[X] unclassified/unlimited [ ] same as report [ ] DTIC users | 21 Abstract Security Classification<br>Unclassified | |
| 22a Name of Responsible Individual<br>Suh, M. | 22b Telephone (*Include Area code*)<br>(408) 646-2637 | 22c Office Symbol<br>AS/Su |

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted — security classification of this page

All other editions are obsolete — Unclassified

Approved for public release, distribution is unlimited.

ANALYSIS OF END-TO-END PERFORMANCE OF LAN SYSTEMS

Chih-Lun Chou
Lieutenant Commander, Republic of China Navy
B.S., Chinese Naval Academy, 1980

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN TELECOMMUNICATIONS
SYSTEMS MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
MARCH 1990

Author: Chih-Lun Chou
Chih-Lun Chou

Approved By: Myung W. Suh
Myung W. Suh, Thesis Advisor

Gary Poock
Gary K. Poock, Second Reader

David R. Whipple, Chairman,
Department of Administrative Sciences

## ABSTRACT

The analysis of LAN performance is the main objective of this research. LANs can be configured in various ways combining different medium access control mechanisms and different physical layer specifications. Details on these alternatives are specified in IEEE 802.3 through IEEE 802.5. We study the performance of different types of LANs under various configurations of servers and stations. The queueing network model is one of the analytical tools to help investigate the performance characteristics of various LAN configurations. Since the analytical approach based on queueing network models is often too complicated to be practically used, we rely on simulations. Thus our analysis will be based on simulations, and SIMLAN II will be the simulation tool for our work. Our specification of simulation models involves three classes of transactions, and one or two servers. There are 24 simulation results in this thesis. These results, which are arranged in tables and figures, help compare the performance characteristics of various LAN configurations.



DTIC
COPY
INSPECTED
1

A-1

TABLE OF CONTENTS

## ABBREVIATIONS

| | |
|---|---|
| AC | Access Control. |
| ASK | Amplitude-Shift Keying. |
| AUI | Attachment Unit Interface. |
| AUI | Attachment Unit Interface. |
| AVG | Average. |
| bps | Bits per seconds. |
| CATV | Cable Antenna Television. |
| CBX | Computerized Branch Exchange. |
| CPU | Central Processing Unit. |
| CSMA/CD | Carrier-Sense Multiple Access with Collision Detection. |
| DA | Destination Address. |
| DA | Destination Address. |
| DTE | Data Terminal Equipment. |
| E-Mail | Electronic Mail. |
| ED | Ending Delimiter. |
| EFS | End-of-Frame Sequence. |
| FC | Frame Control. |
| FCS | Frame-Check Sequence. |
| FDM | Frequency Division Multiplexing. |
| FESC | Flow Equivalent Service Center. |
| FS | Frame Status. |
| FSK | Frequency-Shift Keying. |
| GHz | Gigahertz. |

| | |
|---|---|
| I/O | Input/Output. |
| IEEE | Institute of Electrical and Electronics Engineering. |
| INFO | Information. |
| ISO | International Organization for Standardization. |
| Kbps | Kilobits per second. |
| KHz | Kilohertz. |
| km | Kilometers. |
| LAN | Local Area Network. |
| LED | Light Emitting Diode. |
| LLC | Logical Link Control. |
| LSB | Least Significant Bit. |
| MAC | Medium Access Control. |
| MAC | Medium Access Control. |
| MAP | Manufacturing Automation Protocol. |
| MAU | Medium Attachment Unit. |
| MAX | Maximum. |
| MB | Megabyte. |
| Mbps | Megabits per second. |
| MDI | Medium Dependent Interface. |
| MHz | Megahertz. |
| MIC | Medium Interface Connector. |
| MIN | Minimum. |
| MSB | Most Significant Bit. |
| MVA | Mean Value Analysis. |
| NBS | National Bureau of Standards. |

| | |
|---|---|
| NMT | Network Management. |
| OSI | Open Systems Interconnection. |
| PAD | Packet Assembler/Disassembler. |
| PBX | Private Branch Exchange. |
| PCM | Pulse Code Modulation. |
| PDU | Protocol Data Units. |
| PHY | Physical. |
| PLS | Physical Layer Signaling. |
| PMA | Physical Medium Attachment. |
| PSK | Phase-Shift Keying. |
| SA | Source Address. |
| SA | Source Address. |
| SD | Starting Delimiter |
| SDF | Statistical Distribution Function. |
| SDU | Service Data Unit. |
| SFD | Start Frame Delimiter. |
| SFS | Start-of-Frane Sequence. |
| STD DEV | Standard Deviation. |
| TCP | Transport Control Protocol. |
| TCU | Trunk Coupling Unit. |
| TOP | Technical and Office Protocol. |

# I. INTRODUCTION

Local Area Networks (LAN) proliferate across the world as the demands for end-user computing and information sharing rise at an ever-increasing rate. LAN has been established for research, business operations, manufacturing and many other purposes. Various LANs products are available in the market to meet customer demands. The primary benefits of LAN consist in sharing computer resources such as disks, printers, and modems. Information exchange such as electronic mail, file transfer, and other forms of data are other benefits of LAN. The problem to be addressed in this thesis is: what is the optimal configuration of LAN that can be best meet various user demands.

In Chapter II, we discuss LAN standards. There are two organizations that set forth the standards for LAN: ISO (International Organization for Standardization) and the IEEE (Institute of Electrical and Electronics Engineers) 802 Committee. In LAN protocol architecture as envisioned by ISO and IEEE 802, the data link layer is divided into the LLC (Logical Link Control) layer and MAC (Medium Access Control) layer. The function and specification of MAC and LLC will be described in detail in a subsequent chapter. We are particularly interested in two kinds of LAN in this thesis: the CSMA/CD (Carrier-Sense Multiple Access with Collision Detection) bus and the Token Ring. Detailed descriptions of MAC and physical layers for CSMA/CD bus and Token Ring in accordance with IEEE standards will be presented.

This thesis will discuss a queueing network model that can analyze the performance of different LAN configurations. The model will involve either one or two servers in the LAN for multiple transaction classes. The three classes of transaction to be considered for our study are simple file access application, e-mail and file transfer. The number of PCs on the LAN will be assumed to be ten, twenty or thirty, to represent different traffic loads. These are typical configurations of LAN at school, lab, or in the office. FESC (Flow Equivalence Service Center) can simplify the operations of CPU, disk, LLC and MAC as simple queues. The request delay, LAN utilization and delivery time will be measured for the purpose of the performance analysis of LANs.

Since the analytical approach based on queueing network models is often too complicated to be practically used, we will rely on simulations using SIMLAN II which is a simulation package developed by CACI Products, Inc.,to help analyze LAN performance with an aid of graphic interface. It took us more than 100 hours of simulation on the IBM PS/2 model 80 to get results for this thesis. We made 24 different simulations and their results are summarized in 34 tables and figures in Chapter IV. Another 30 tables and 28 figures are given in Appendix A as supplementary data. SIMLAN II printouts for these simulations are attached in Appendix B.

## II . OVERVIEW OF LOCAL AREA NETWORKS

### A. LAN ARCHITECTURE

A local area network provides the sharing of system resources such as disks, printers, and information. The architecture of LAN refers to the hardware and software infrastructure which will determine the accuracy, speed, resource sharing, security for the data transmission in the LAN.

LAN may have various topologies. Examples are star, tree, ring, bus and mesh topologies. For the star network, the switchboard operator connects customer calls by PBX (Private Branch Exchange) or CBX (Computerized Branch Exchange). All messages pass through the central switching station in the center of the star. It can transmit digital data and/or voice data. The topology of a star network is shown in Figure 1.

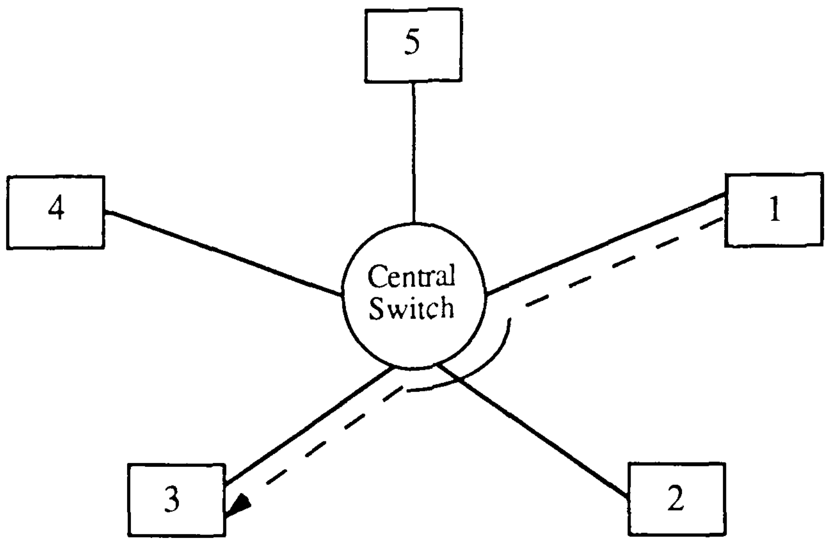



**Figure 1. Star Network** [Ref. 3:p. 76]

A tree network allows information flow through branches. Its topology is shown in Figure 2. All information must pass through many branches and switches to move from one node to another. To move from point one to point two in Figure 2, the data must travel through eight switches. A tree network is suitable for functional queueing. It tends to isolate the hardware problems and one branch can stop functioning without bringing down the entire network. This hierarchical structure has the greatest strength and reliability.

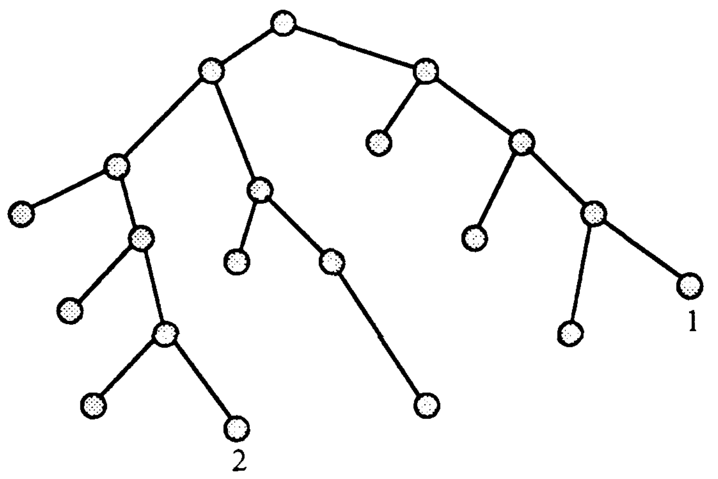



**Figure 2. Tree Network** [Ref. 3:p. 77]

A ring network can be unidirectional or bidirectiional. All nodes are in a closed loop or circle. A unidirectional ring moves in only one direction; a bidirectional ring moves in either direction but only moves in one direction at a time. The ring network (Figure 3) can send data faster as node 1 can send data to node 6 without moving past nodes 2 through 5. Medium access control is implemented by the token. The token is the permission to send data. The receiving node gets the token; it reads the address and data packet, then marks it as having been read and puts it back in the network. When the sender node sees its packet with the "been read" notation, it removes the packet and releases the token. The disadvantage of ring architecture is the practical upper limit on the size of the loop.

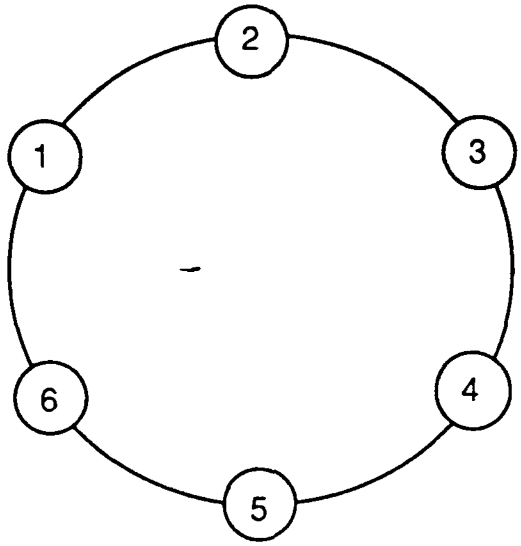



**Figure 3. Ring Network** [Ref. 3:p. 78]

The advantage of the bus network is its passive nature. All devices can communicate with other devices in the network. To add another node, we simply add the new node and update the system list to include the new address without changing the structure. If a station needs repair, it does not affect the whole network. There are some buses using the token-passing mechanism as in the token ring. The topology of the bus network is shown in Figure 4.

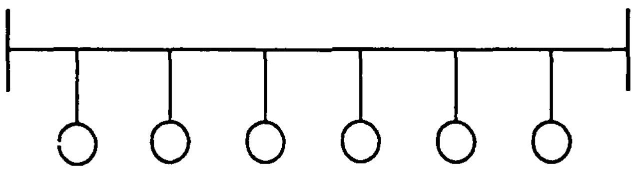


**Figure 4.** **Bus Network** [Ref. 2:p. 9]

The architecture of the physical star/logical ring is like a physical star but handles data like a ring. It uses a token-passing control scheme in which a token passes from address to address to give the successive address permission to send data. All data must move through the central hub. It is inexpensive like the physical star and has the great flexibility of a token-pass ring. The scheme of the physical star/logical ring network is shown in Figure 5.

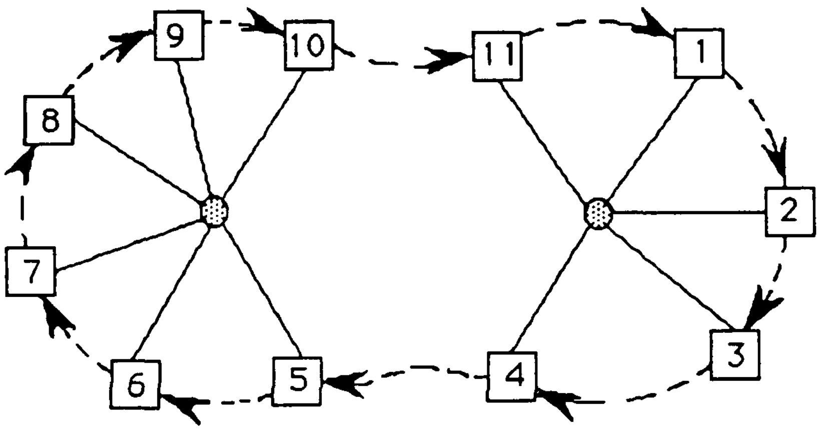



**Figure 5. Physical Star/Logical Ring Network** [Ref. 3:p. 79]

There are also complex networks such as the mesh and multi-bus networks. The mesh network connects with every node directly (Figure 6). Due to its complexity and costs, this type of network is not popular. The multi-bus architecture creates a bridge to connect two or more buses (Figure 7). Since most single buses can support over 100 devices, the multi-bus can support an even larger number of connections. [Ref 3:p. 75-81]

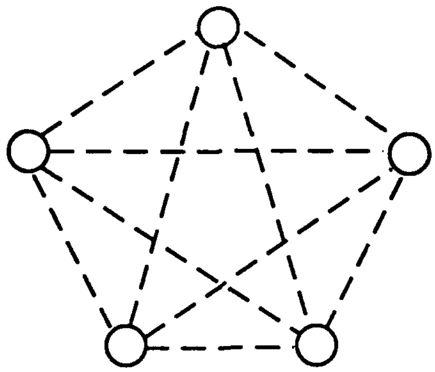


Figure 6. Mesh Network [Ref. 3:p. 80]

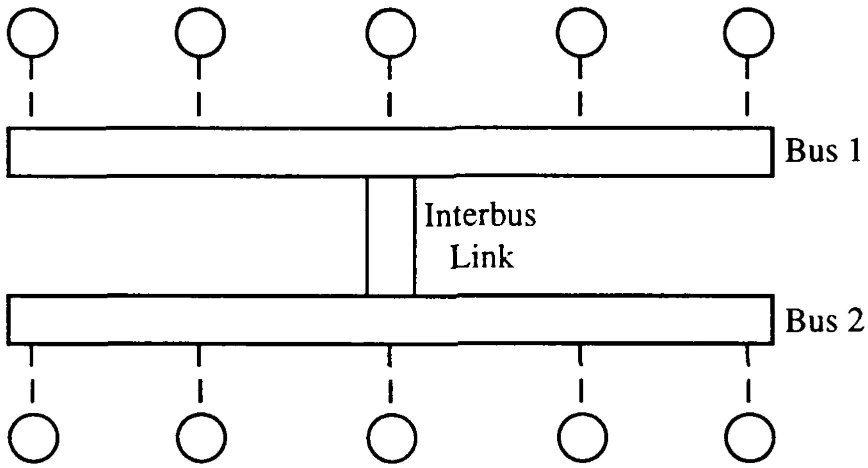



Figure 7. Multi-Bus Network [Ref. 3:p. 80]

## B. LAN STANDARDS

### 1. The OSI Reference Model and LAN

LAN standards deal with physical media, medium access control, and other aspects of data transmission on LAN. The current LAN standards support in layer 1, 2 and 3 of OSI Reference Model, which is three different types of LAN: CSMA/CD bus, token bus, and token ring. The seven sublayers of the OSI reference model are described in Figure 8. The IEEE (Institute of

Electrical and Electronics Engineers) 802 project is an attempt to standardize the physical and data link layers of the OSI (Open System Interconnection).

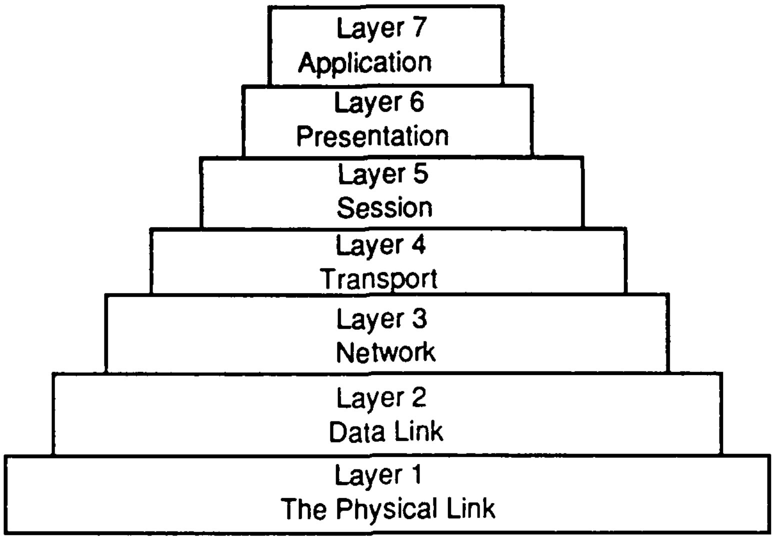



**Figure 8. Open System Interconnection Model** [Ref. 4:p. 23]

The purpose of the ISO OSI reference model is to ensure information flow among systems and permit variations in basic communication technology at the same time. Each layer functions as follows: [Ref. 4:p. 22-23]

- The **application layer** provides access to the OSI environment for users and distributes information services.
- The **presentation layer** provides independence to the application processes from differences in data representation (syntax).
- The **session layer** provides the control structure for communication between applications; establishes, manages, and terminates the connections (session) between cooperating applications.
- The **transport layer** provides reliable, transparent transfer of data between end-to-end points with end-to-end error recovery and flow control.
- The **network layer** provides upper layers with independence from the data transmission and switching technologies used to connect systems; it is responsible for establishing, maintaining, and terminating connections.

- The **data link layer** provides for the reliable transfer of information across the physical link; sends blocks of data (frames) with the necessary synchronization, error control, and flow control.
- The **physical layer** is concerned with transmission of unstructured bit streams over physical mediums; deals with mechanical, electrical, functional, and procedural characteristics to access the physical medium. [Ref. 2:p. 12]

ISO standards promote the inter-operability in multi-vendor heterogeneous environments. The OSI standards have been incorporated into the National Bureau of Standards' (NBS) *Federal Information Processing Standards*. It is also a key factor in developing Manufacturing Automation Protocol (MAP) and Technical/Office Protocol (TOP). IEEE standards for LAN have been adapted as part of ISO standards.

Three layers are involved in the local network model are as follow:

- The physical layer deals with the nature of the transmission medium, electrical signaling, and device attachment.
- Medium access control layer regulates access to sharing a single medium.
- Logical link control layer regulates the establishment, maintenance, and termination of the logical link between devices.

The relationship between the IEEE 802 standards and the OSI Reference Model is depicted in Figure 9. The advantage of standards is that the standards allow various manufacturers to produce compatible devices. And the strategy of the IEEE 802 committee is to provide a flexible framework for LANs. Different manufacturers can produce compatible devices which are suitable for the multi-vendor environment. [Ref. 4:p. 25-26]

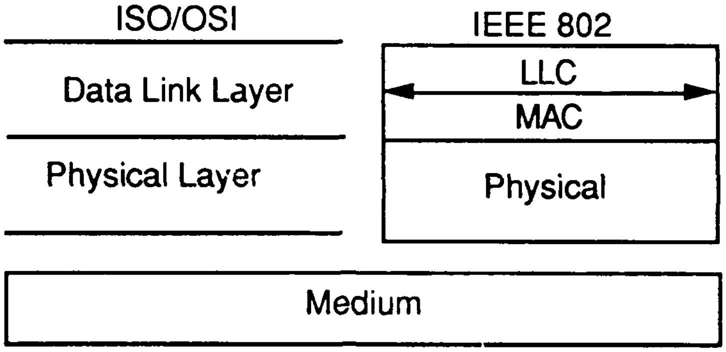



**Figure 9. IEEE 802/OSI Reference Model** [Ref. 4:p. 26]

### 2. Transmission Media for LAN

IEEE 802.3 standards were developed in a flexible fashion. In 1986, standards were ready for the twister pair, coaxial cable, and optical cable. Especially, coaxial cable is available for the original 50 ohm baseband and the 70 ohm CATV (Cable Antenna Television) meets broadband standards. This same development pattern applies to the 802.4 and 802.5 standards. The optic cable will become more important in the 1990s.

#### *a. Twisted Pair*

The most common medium for LAN is the twisted pair. Even though the modern telephone system uses various forms of media, telephone technology is logically based on the twisted pair and the cable using two pairs of copper wire. Effectiveness of the copper wire is limited by the sheathing material which causes distortion that increases with distance and speed. Thus it limits the data rate and bandwidth. [Ref. 4:p. 27]

The size of the twisted pair is from 0.016 to 0.036 inches. It can be used for digital and analog signaling. For digital signals, repeaters are used every 2 or 3 km. For analog signals, amplifiers are required about every 5 or 6 km. The standard bandwidth of a full-duplex voice is 300 to 3000 Hz. It has a capacity of up to 24 voice channels, using a bandwidth of up to 268 KHz. Multiple voice channels use frequency-division multiplexing on a single wire pair.

Digital signals using a modem are transmitted over an analog voice channel. The speed is up to 9600 bps when Phase Shift Keying is used. T1 circuits can handle a 24 PCM (Pulse Code Modulation) voice channel for the data rate of 1.544 Mbps.

The twisted pair can easily provide point-to-point data transmission to a range of 15 km or more. Crosstalk can interfere with signals on adjacent cables. The cost of installation is relatively high and may approach the cost of other media. [Ref. 5:p. 7-8]

*b. Coaxial Cable*

The practical alternative to twisted pair is the coaxial cable for the broadband and baseband system. It has a single center conductor, surrounded by an insulator, surrounded by a wire-mesh shield. Coax can handle greater bandwidth and signals at radio frequency. Coaxial cable can be classified by physical size and impedance. [Ref. 4:p. 27-28]

The diameter of a single coaxial cable is from 0.4 to about 1 inch. The 50 ohm cable is used for digital transmission, which is by Manchester encoding. The data rate is up to 10 Mbps. 75 ohm CATV cable is used for both digital and analog signaling for frequencies up to 300 to 400 MHz. CATV cable uses FDM (Frequency Division Multiplexing) for broadband. ASK, FSK, and PSK are used for the digital data transmission. The maximum data rate is up to 20 Mbps by current technology. The distance of baseband cable is limited to a few meters. Broadband cable can span ranges of tens of kilometers. The expense of installing coaxial cable is between the twisted pairs and optical fiber. [Ref. 5:p. 8-10]

*c. Optical fiber cable*

In the mid-1980s, the primary problem of the fiber-optic cable was that devices for splicing and tapping cable were expensive and difficult to use. Since the connecting devices were not standardized for optic cable, it is still expensive to transmit the data over optic fiber. But it solves the problems of twisted pairs and the coaxial cable, and also provides a high data rate for transmission. The network can be designed with a substantially smaller amount of cable. [Ref. 4:p. 27-29]

Optic fiber is a thin (2 to 125 μm), flexible medium for conducting the optical ray. The fibers of ultrapure fused silica provide the lowest losses. Ultrapure fiber is difficult to manufacture, so the cost is high. Using the higher-loss multicomponent glass fibers is more economical and still allows good performance. Plastic fiber has moderately high loss, is less costly and is used for short-haul links.

The optical fiber consists of the core, cladding and jacket. Its transmission modes are classified as step-index multimode, graded index multimode, single mode. The step-index and graded-index multimode use the LED (Light Emitting Diode) or laser for a light source. The bandwidth of step-index multimode is up to 200 MHz/km and thus used for computer data links. The bandwidth of graded-index multimode is from 200 MHz to 3 GHz/km and used for moderate length telephone lines. The bandwidth of single mode is from 3 GHz to 50 GHz/km and is used for telecommunication long lines. [Ref. 5:p. 10-14]

### 3. Media Access Control (MAC)

The media access control in LAN is concerned with the methods by which the nodes transmit on the channels. Two primary methods used are the Carrier Sense Multiple Access/Collision Detection (CSMA/CD) and token passing. The 802.3 standard addresses CSMA/CD, while 802.4 and 802.5 deal with token passing. IEEE 802.3 standard is a bus using CSMA/CD as a medium access control method. IEEE 802.4 standard is a bus using token passing as a medium access control method. IEEE802.5 is a ring using token passing as an access method. [Ref. 4:p. 29]

The MAC technique for the ring/tree topologies is CSMA/CD, which is referred to as listen while talk. The rules of CSMA/CD as below:

- If a collision is detected during transmission, immediately stop transmitting the packet, and transmit a brief jamming signal to assure that all stations know there has been a collision.
- After transmitting the jamming signal, wait a random amount of time, then attempt to transmit again using CSMA. [Ref. 2:p. 349-350]

### 4. Logical Link Control (LLC)

The Logical Link Control (LLC) is the part of data stations that supports the logical link function of one or more links. The responsibilities of an LLC include

- Initiation of control signal interchange.
- Organization of data flow.
- Interpretation of received command PDUs (Protocol Data Units) and generation of appropriate response PDUs.
- Error control and recovery functions in the LLC.

There are two primary services in the LLC: 1) the unacknowledged connectionless service and 2) connection-oriented service. The unacknowiedged connectionless service uses the datagram to send and receive LLC frames with no acknowledgment for assured delivery. It can support all forms of connection, that is point-to-point, multipoint, broadcast, and multiplexed. The connection-oriented service provides a virtual circuit form of connection between service access points. The result of this service is sequencing, flow control, and error recovery. The connection-oriented services are connection establishment, connection reset, connection termination, and connection flow control. [Ref. 4:p. 30]

## C. CSMA/CD (IEEE 802.3) SYSTEMS

### 1. Overview

The easiest way to establish an LAN is the Ethernet (802.3). It is the most widely deployed and supported system. The International Standard Organization (ISO) and IEEE 802 have standardized the Ethernet as CSMA/CD in 1983. It provides the interconnection of equipments from different vendors. In 1986, IBM introduced the 9370 office microcomputer with both Ethernet and Token Ring. The CSMA/CD system can easily change or enlarge the number of nodes. On the other hand, the token ring has deterministic qualities and presents configuration problems in some environments.

The first edition of 802.3 (IEEE Std 802.3-1985) defined a 10 Mbps baseband implementation of the physical layer. It allows for several media types and techniques for data rate from 1 Mbps to 20 Mbps. It uses the Logical Link Control (LLC) and the Media Access Control (MAC) sublayer to support varied transmission media. The Medium Dependent Interface (MDI) and the Attachment Unit Interface (AUI) are defined as compatible interfaces in the physical layer. The transceiver is the small circuit existing in the Medium Attachment Unit (MAU) of baseband Ethernets. [Ref. 4:p. 112-117]

### 2. Media Access Control (MAC)

The functions of MAC consist of various services, frame structures, and a MAC method. Each function will be described below:

The basic services are MA_DATA.request, MA_DATA.confirm, MA_DATA.indication. The MA_DATA.request defines the transfer of data from a local LLC sublayer entity to a single peer LLC entity or multiple peer LLC entities in the case of group addresses. The elements of MA_DATA.request are Destination Address (DA), Service Data Unit (SDU), Service Class. The function of the MA_DATA.confirm primitive is to provide an appropriate response to the LLC sublayer MA_DATA.request. Transfer of data from the MAC to the LLC sublayer is defined by the MA_DATA,indication primitive. It consists of Destination Address (DA), Source Address (SA), Service Data Unit (SDU), Reception Status.

In an LAN, data is transmitted in a highly structured format, referred to as a frame or packet. The frame is defined by the use of octets. The maximun frame size is 1518 octets, and the minmum is 64 octets. The format of frame consists of preamble, start frame delimiter, address fields, length, data and PAD fields, and frame check sequence.

The medium access control method is performed by the LLC and MAC sublayer. The sublayers of LLC and MAC have the same functions as the OSI Data Link Layer. Medium access control handles medium allocation (collision avoidance) and contention resolution (collision handling). The Physical Layer Signaling (PLS) component of the Physical Layer is an interface between the MAC sublayer and the Physical Layer. It allows the serial transmission of bits onto the physical medium. The main functions of CSMA/CD are frame transmission, frame reception and flow control. [Ref. 4:p. 117-126]

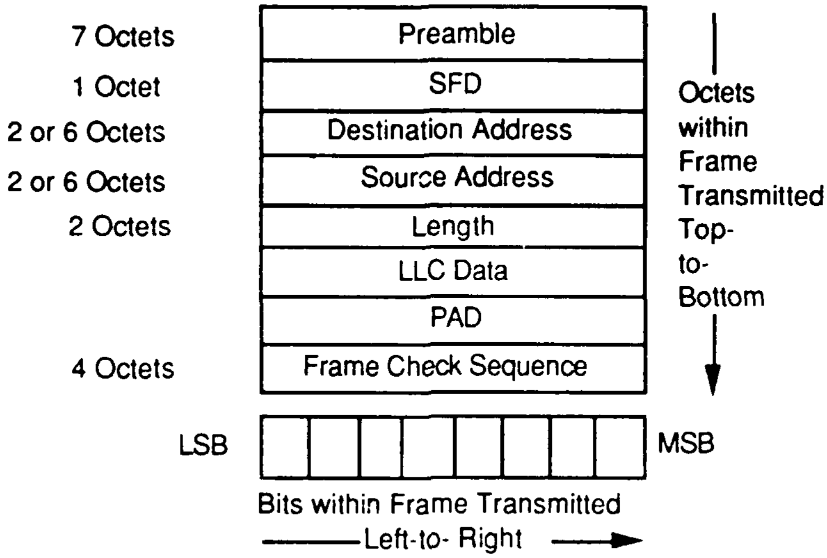



**Figure 10. CSMA/CD MAC Frame Format** [Ref. 4:p. 120]

### 3. Physical Layer

The Physical Layer consists of Physical Layer Signaling (PLS), Attachment Unit Interface (AUI), and Physical Medium Attachment (PMA). For the PLS, the primary functions are the communication of peer-to-peer (station-to-station) and sublayer-to-sublayer. The functions of the peer-to-peer communication are PLS_DATA.request, PLS_DATA.confirm, and PLS_DATA.indication. The functions of sublayer-to-sublayer are PLS_CARRIER.indication and PLS_SIGNAL.indication.

The AUI consists of the cable, connectors, and transmission circuitry used to interconnect the PLS and MAU (Medium Attachment Unit). The AUI provides one or more of the defined data rates. It is capable of driving up to 50 meters; it permits the Data Terminal Equipment (DTE) to test the AUI, AUI cable, Medium Attachment Unit (MAU), and the medium itself.

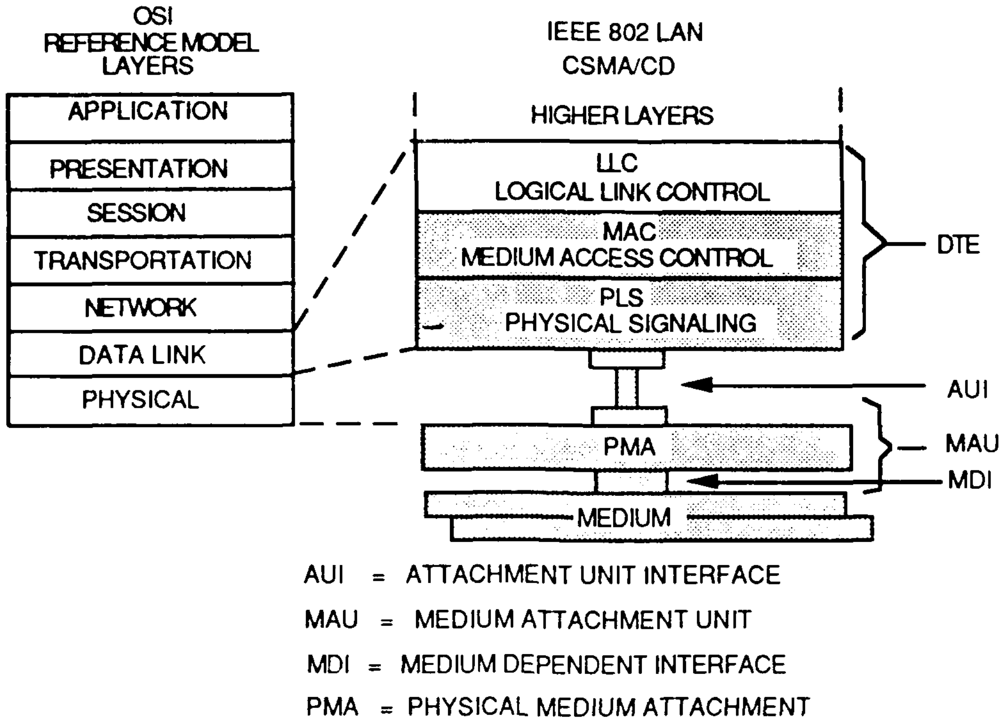



**FIGURE 11. IEEE 802.3 Architecture** [Ref. 5:p. 85]

The MAU is the portion of the physical layer between the Medium Dependent Interface (MDI) and AUI that interconnects the cables. The MDI is the mechanical and electrical interface between the trunk cable medium and the MAU. Each Ethernet trunk segment can be only 500 meters, and up to 2.5 kilometers or five segments for the baseband system. MAUs connect to the trunk system at a minimum interval of 2.5 meters, and with no more than 100 MAUs per 500-meter segment. The transceiver usually contains physical connections to the trunk cable and the MAU circuitry.

## D. TOKEN RING (IEEE 802.5) SYSTEMS

### 1. Overview

A token ring LAN is made up of a set of stations serially connected by a transmission medium. All information is transferred serially bit by bit from one active station to the next. The token is a symbol of authority for stations to indicate which station is currently in control of the medium. Actually, the token is a signal consisting of a unique sequence circulating on the medium. The services are set by different levels of priority which can be assigned independently and dynamically. The broken ring may cause the LAN to shut down. [Ref. 4:p.160-2]

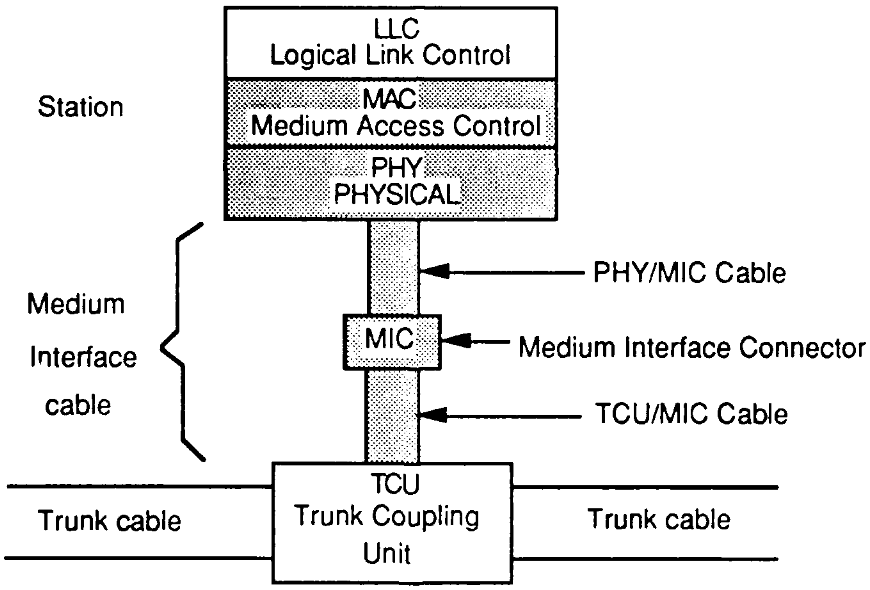



**Figure 12. IEEE 802.5 Architecture** [Ref. 5:p.149]

The IEEE 802.5 standard can be viewed as MAC service specification, MAC protocol, physical layer entity specification, station attachment specification. The MAC service specification defines the function to logical link control or any other higher-level user. The MAC protocol defines the frame structure and the interactions that take place between MAC entities. The physical layer specification consists of a medium-independent part and a medium-dependent part. The medium-independent part specifies the service interface between the MAC and the physical layers. The medium-dependent part specifies the functional, electrical, and mechanical characteristics of medium attachment. The station attachment includes the trunk coupling unit and medium itself.

### 2. Media Access Control

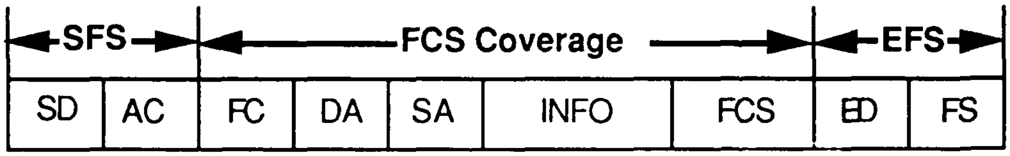
The token ring techniques are based on the token circulating around the ring when all stations are idle. Any station to transmit waits until it detects a token passing. It then changes the token to a start-of-frame sequence and appends the remainder of the frame. Later, the destination station copies the frame addressed to it, and the sender generates a token upon receipt of the physical transmission header. There is now no *token on the ring*. The transmitting station inserts a new token on the ring when the following conditions have been met

- The station has completed transmission of its frame.
- The leading edge of its transmitted frame has returned to the station.

The MAC frame format consists of the following fields: starting delimiter, access control, frame control, destination address, source address, information, frame check sequence, ending delimiter, and frame status. Figure 13 shows the structure of frame format.

The MAC frame information field is related to the particular control message. It consists of vector length, vector identifier, subvector length, subvector identifier, and subvector value. The IEEE 802.5 standard provides for eight levels of priority. It gives two 3-bit fields in each data frame and token: a priority field and a reservation field.

The MAC services provided by the MAC layer allow the local LLC entity to exchange LLC data units with peer LLC entities. There are MA_DATA.request, MA_DATA.indication and MA_DATA.confirmation provide services to the LLC sublayer. The MA_DATA.request consists of frame_control, destination_address, m_sdu and requested_service_class. The MA_DATA.indication consists of frame_control, destination_address, source_address, m_sdu, and reception_status. The MA_DATA.indication consists of transmission_status and provided_service_class. Network management monitors and controls the operation of the MAC sublayer. MAC provides services to reset MAC and to change MAC operational parameters.




SFS = Start-of-Frane Sequence
SD = Starting Delimiter (1 octet)
AC = Access Control (1 octet)
FC = Frame Control (1 octet)
DA = Destination Address (2 or 6 octets)
SA = Source Address (2 or 6 octets)
INFO = Information (0 or more octets)
FCS = Frame-Check Sequence (4 octets)
EFS = End-of-Frame Sequence
ED = Ending Delimiter (1 octet)
FS = Frame Status (1 octet)

**Figure 13. IEEE 802.5 Frame Format** [Ref. 5:p. 152]

### 3. Physical Layer

All the suitable media (twisted pairs, coaxial cable, and optical fiber) can be used for connecting stations, through the standard attachments for the future. The standards define the data rates of 1, 4, 16 Mbps and the maximum number of stations specified is about 250. The physical layer is specified by data symbol encoding and decoding, symbol timing, and reliability. To recover the symbol timing is a main objective of the physical layer. It requires a latency buffer to provide assured minimum latency and phase jitter compensation. Latency is a phenomenon for the token to continuously circulate around the ring. Jitter is instability in a signal waveform over time due to signal interference.

Physical layer services can be specified as PHY to MAC service and PHY to NMT service. The PHY layer provides the request, indication, and confirmation for the MAC sublayer. MAC sends a request to PHY as a symbol output; PHY encodes and transmits the symbol. When the PHY is ready to service another request, it returns a confirmation to MAC. The indication defines the transfer of data from PHY to MAC.

The services provided by PHY to NMT allow the local NMT to control the operation of the PHY layer. PHY use PH_CONTROL.request and PH_STATUS.indication as main services. NMT requests the PHY layer to insert itself into or remove itself from the ring. This indication is used by PHY to inform NMT of errors and significant status changes through the "status_report." [Ref. 4:p.160-p.180] [Ref.5:p.148-p.174]

# III. QUEUEING NETWORK MODELING OF LAN

## A. THE FUNDAMENTAL LAW

### 1. Utilization Laws

The utilization of a system is an important parameter in a queueing network model. In order to explain the utilization law, we define the following variables in an abstract system as shown in figure 3.1.

T, the length of time for which the system is observed.

A, the number of request arrivals observed during T.

C, the number of request completions observed during T.

B, the length of time that the resource was observed to be busy.

$\lambda$, arrival rate: $\lambda \equiv \frac{A}{T}$

X, throughput: $X \equiv \frac{C}{T}$

U, utilization: $U \equiv \frac{B}{T}$

S, the average service requirement per request: $S \equiv \frac{B}{C}$

The Utilization Law is represented by the following equation: $U = XS$. That is, the utilization of a resource is equal to the product of the throughput of that resource and the average requirement at that resource.

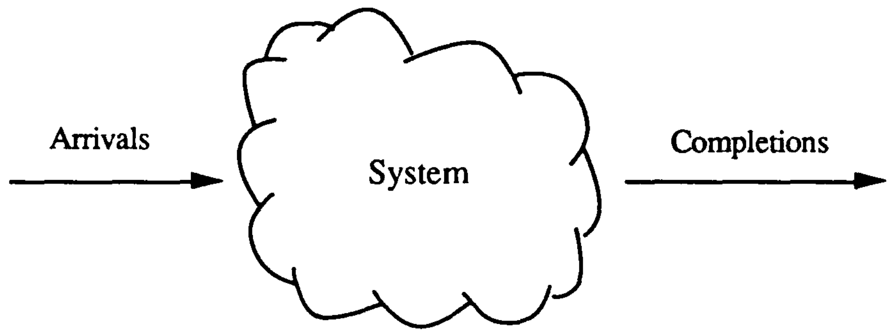



**Figure 14. An Abstraction System** [Ref. 1: p. 41]

### 2. Little's Law

The utilization law in fact is a special case of Little's Law. For a particular time interval, we accumulate elapsed time between request arrivals and completions measured in request-seconds (or request-minutes, etc.).

The following variables are used to define Little's Law.

W, the accumulated time in the system.

N, the average number of requests in the system: $N \equiv \frac{W}{T}$

R, the average system residence time per request: $R \equiv \frac{W}{C}$

Algebraically, $\frac{W}{T} = \frac{C}{T}\frac{W}{C}$. But $N \equiv \frac{W}{T}$, $X \equiv \frac{C}{T}$, and $R \equiv \frac{W}{C}$.

Thus Little's Law is given as follows: $N = XR$.

That is, the average number of requests in a system is equal to the product of the throughput of that system and the average time spent in that system by a request. One important point of Little's Law is that the quantity R does not necessarily correspond to our intuitive notion of average residence time or response time--the expected time from arrival to departure. The diagram of system arrivals and completions is given below:

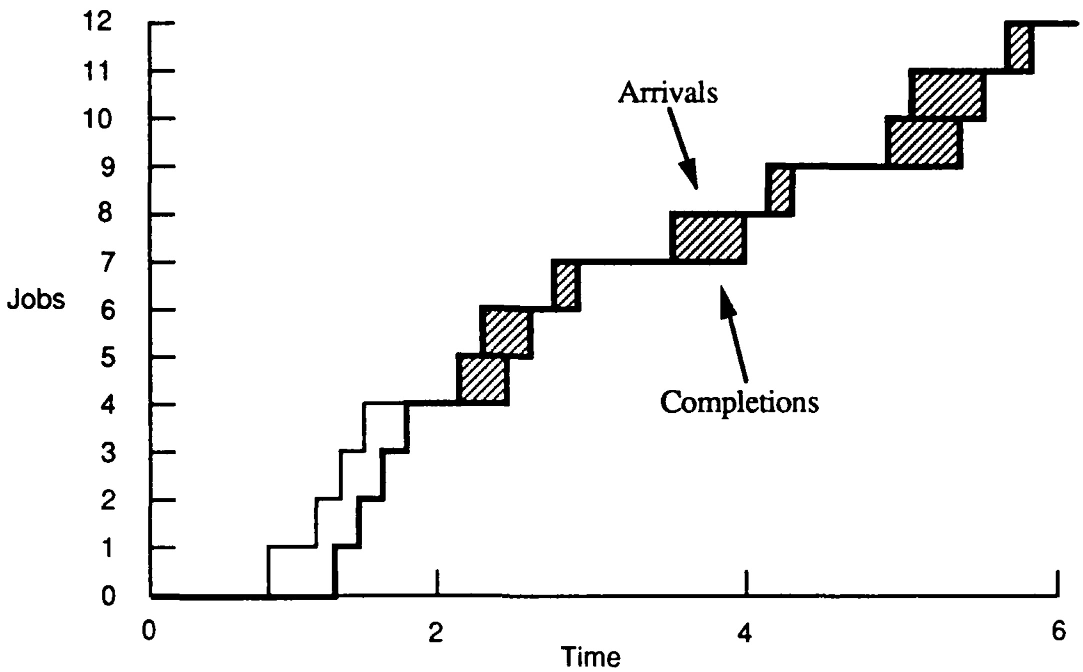



**Figure 15. System Arrivals and Completions** [ Ref. 1: p. 43]

Little's Law is important for three reasons. First, because it is so widely applicable (it requires only very weak assumptions), it will be valuable to us in checking the consistency of measured data. Second, in the study of computer systems we frequently find that we know the average number of requests in a system and the throughput of that system, and desire to know the average system residence time. Third, Little's Law is central to the algorithms for evaluating queueing network models. For a computer system, Little's Law can be applied at many different levels--to a single resource, to a subsystem, or to a system as a whole.

The key to success is consistency. The definitions of population, throughput, and residence time must be compatible with one another. Figure 16 illustrates this by applying Little's Law to a hypothetical timesharing system at four different levels as indicated by the four boxes.

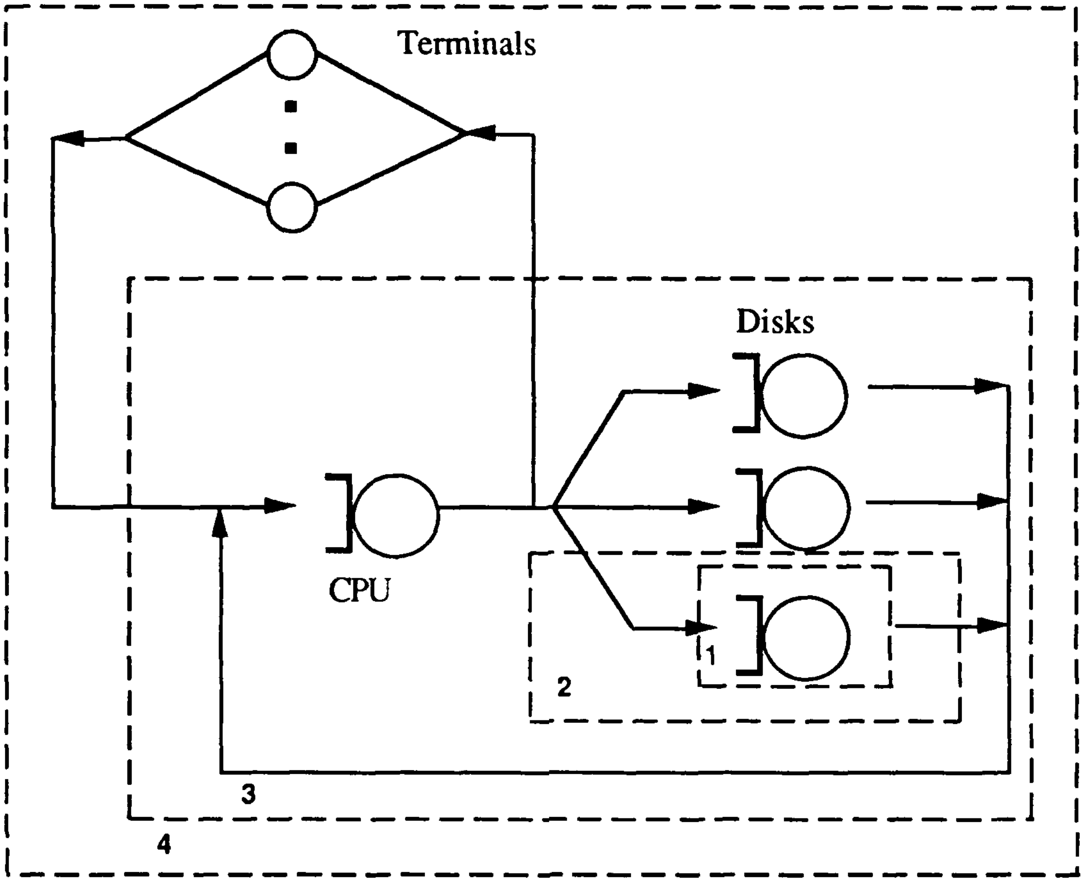



**Figure 16. Little's Law Applied at Four Levels** [Ref. 1: p. 44]

Box 1 illustrates the application of Little's Law to a single resource, not including its queue, and the population corresponds to the utilization of the resource.

Box 2 illustrates the application of Little's Law to the same resource, this time including its queue. The population corresponds to the total number of requests either in queue or in service; throughput is the rate at which the resource is satisfying requests; and residence time corresponds to the average time that a request spends at the resource per visit including both queueing time and service time.

Box 3 illustrates the application of Little's Law to the central subsystem, the system without terminals. Here, the requests are system-level interactions. Throughput corresponds to the rate at which interactions flow between terminals and the central system. Residence time corresponds to our conventional notion of response time.

Box 4 illustrates the application of Little's Law to the entire system, including its terminals. Here, population corresponds to the total number of interactive users, throughput corresponds to the rate at which interactions flow between the terminals and the system, and residence time corresponds to the sum of system response time and user think time. If we denote think time by Z, then we can write this interaction of Little's Law as $N = X\,(R+Z)$. As with the utilization law, this application is so ubiquitous that R is shown in terms of quantities N, X and Z:

The Response Time Law: $R = \frac{N}{X} - Z$.

### 3. The Forced Flow Law

When considering an entire system, on the other hand, it is natural to define a request to be a user-level interaction and to measure throughput and residence time on this basis. The relationship between these two views of a system is expressed by the forced flow law, which states that the flows (throughputs) in all parts of a system must be proportional to one another. Define the visit count of a resource to be the ratio of the number of completions at that resource to the number of system completions, or, more intuitively, to be the average number of visits that a system-level request makes to that resource. Thus if we define the variable $V_k$, the visit count of resource k: $V_k \equiv \frac{C_k}{C}$, then we can rewrite above formula as $C_k \equiv V_k\ C$.

Accordingly the throughput of resource k is given by:

The Forced Flow Law: $X_k \equiv V_k\ X$.

Little's Law becomes especially powerful when combined with the forced flow law. If the number of terminals and average are known, then one can calculate the throughput for the disk, system, and response time using the follows formulas.

Disk throughput: $X_{disk} = \frac{U_{disk}}{S_{disk}}$

System throughput: $X = \frac{X_{disk}}{V_{disk}}$

Response time: $R = \frac{N}{X} - Z$

The disk service for user-system interaction can be described in the following way. An interaction makes a certain number of visits to the disk and requires a certain amount of service on each visit; so we can specify the total amount of disk service required by an interaction.

$V_k$, visit at resource k

$S_k$, service requirement per visit at resource k

$D_k$, the service demand at resource k: $D_k \equiv V_k\ S_k$

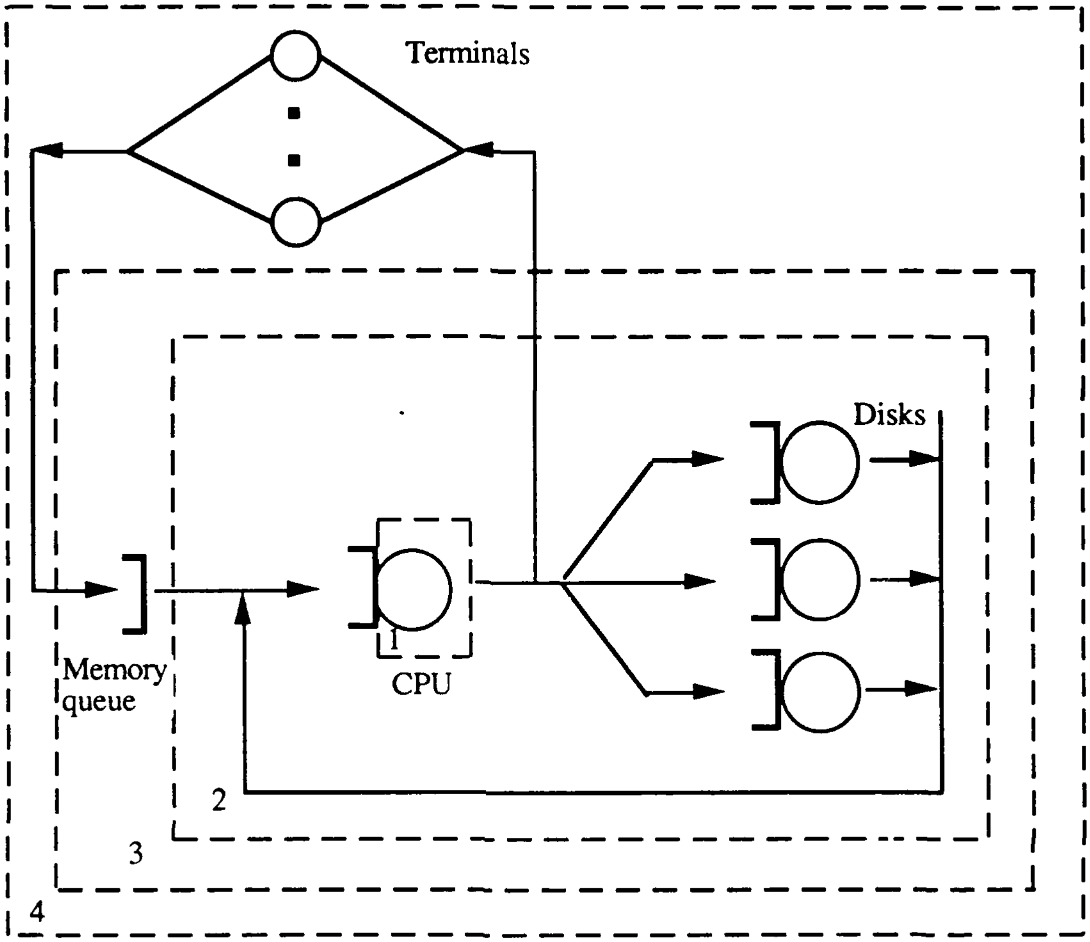



**Figure 17. Little Law Applied to a Memory Constrained System**
[Ref. 1: p. 50]

For a timesharing system with a memory constraint, swapping may occur between interactions, so a request may be forced to queue for a memory partition prior to competing for the resources of the central system. Little's Law can be applied to this system, as shown in Figure 17. For box 4, we can get the average response time for a timesharing user. For box 3, we can get how many users were attempting to obtain service. For box 2 , we can get how much time elapses between the acquisition of memory and the completion of an interaction. For box 1, we can get the contribution to CPU utilization of the timesharing workload.

### 4. The Flow Balance Assumption

If the flow balance property is satisfied, the number of arrivals equals the number of completions, and thus the arrival rate equals the throughput:

The Flow Balance Assumption: $A = C$, therefore $\lambda = X$.

It can be tested over any measurement interval. With the flow balance assumption, Little's Law and the forced flow law can be used for calculating device utilization for a system whose workload intensities are described in terms of arrival rate.

## B. THE QUEUEING NETWORK MODEL

### 1. The Single Class Model

#### *a. Inputs*

The basic entities in queueing network models are service centers which represent system resources and customers which represent users, jobs or transactions. At the inputs of the model, customer described as the workload intensity, it may be described in three ways:

**customer description:** The workload intensity,

$\lambda$,the arrival rate(for transaction work loads),or

N, the population (for batch workloads), or

N and Z, the think time (for terminal workloads).

**center description:**

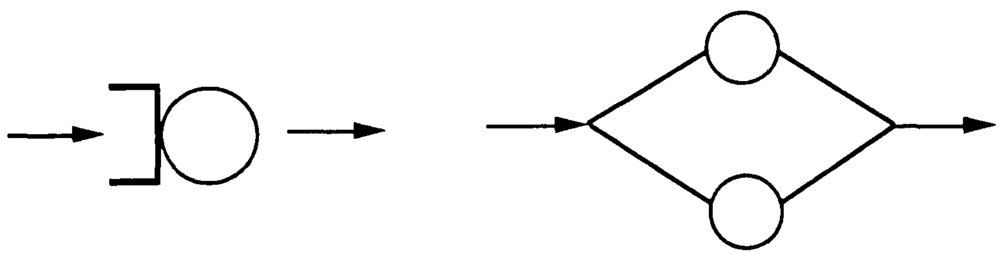
K, the number of service centers. For each service center k: its type, either queueing or delay.

**service demands:**

For each service center k: $D_k \equiv V_k S_k$, the service demand.

The workload can be classified into three groups. First, the transaction workload has its intensity specified by a parameter $\lambda$, indicating the rate at which requests (customers) arrive. Second, the batch workload has its intensity specified by a parameter N, indicating the average number of active jobs (customers). (N needed not be an integer.) Third, the terminal workload has its intensity specified by two parameters: N, indicating the number of active terminals (customers), and Z, indicating the average length of time that customers use terminals ("think") between interactions. (Again, N need not be an integer.)

There are two types of service centers, queueing and delay. They are represented below.



Queueing Center Delay Center

**Figure 18. Queueing and Delay Service Centers** [Ref. 1: p. 59]

Queueing centers are used to represent any system resources. The time spent by a customer at a queueing center has two components, time spent waiting, and time spent receiving service. The most common use of a delay center is to represent the think time of a terminal workload. Thus the residence time of a customer at a delay center is the customer's demand service.

### *b. Outputs*

For evaluating the outputs of a single class queueing network model, there are several parameters for system and center measurement.

**System measures:**

R, average system response time.

X, system throughput.

Q, average number in system.

**Center measures:**

$U_k$, utilization of center k.

$R_k$, average residence time at center k.

$X_k$, throughput as center k.

$Q_k$, average queue length at center k.

The utilization of a center is the average number of users in service. System response time is the interval between submitting a request and receiving a response time on an interactive system. System response time is the sum of the residence times at the various centers. The average queue length at center k includes all customers at the center, whether waiting or receiving service. [Ref. 1: p. 1-p. 62]

## 2. Multiple Class Models

### *a. Inputs*

The multiple class model consists of the workload intensity ($\lambda_c$, $N_c$, or $N_c$ and $Z_c$), and its own service demand at each center ($D_{c,k}$).

**Customer description:**

C, the number of customer classes.

For each classes c; the workload intensity

$\lambda_c$, the arrival rate.

$N_c$, the population (for batch workload).

$N_c$ and $Z_c$, the think time.

**Center description:**

K, the number of service centers.

For each service center k, the type is queueing or delay.

**Service demand:** For each class c and center k:

$D_{c,k} \equiv V_{c,k} S_{c,k}$, the service demand.

*b. Output:*

All performance measurements can be obtained on a pre-class basis as well as on an aggregate basis. For utilization, queue length, and throughput, the aggregate performance measure equals the sum of the pre-class performance measures ($U_k$). Applying Little's Law, the residence time and system response time are shown below.

**System measure:**

aggregate: R, average system response time.

X, system throughput.

Q, average number in system.

per-class: $R_c$, average class c system response time.

$X_c$, class c system throughput.

$Q_c$, average class c number in system.

**Center measure:**

aggregate: $U_k$, utilization of center k.

$R_k$, average residence time at center k.

$X_k$, throughput at center k.

$Q_k$, average queue length at center k.

per class: $U_{c,k}$, class c utilization of center k.

$R_{c,k}$, average class c residence time at center k.

$X_{c,k}$, class c throughput at center k.

$Q_{c,k}$, average class c queue length at center k.

The conclusions as below.

- The basic outputs are average values rather than distributional information.
- $X_k$ and $X_{c,k}$ are meaningful only if the model is parameter in terms of $V_{c,k}$ and $S_{c,k}$.
- Specifying the output values corresponds to a particular workload intensity, then follow the output symbol with the parenthesized workload intensity. [Ref. 1: p. 62-p. 67]

### 3. Network of Queues

The network of queues will be either open or closed systems.

#### *a. Open System*

Consider a two server system. The customer arrival rate is $\lambda$ at server 1. After being served by server 1, the customer joins the queue in front of server 2. Each server serves one customer at a time with a rate $\mu_i$ for server $i$ = 1,2. This system is called a tandem or sequential system.

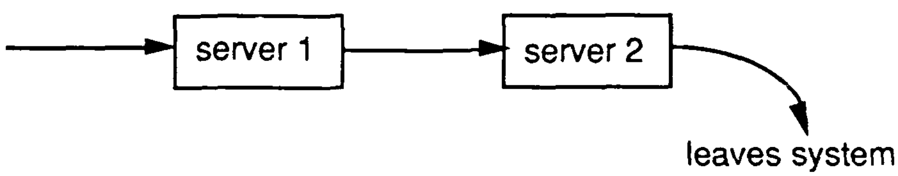



**Figure 19. A Tandem Queue** [Ref. 6: p. 365]

The balance equation is as below:

| **state** | **rate that the process leaves = rate that it enters** |
|---|---|
| 0, 0 | $\lambda P_{0,0} = \mu_2 p_{0,1}$ |
| n, 0; n>0 | $(\lambda + \mu)P_{n,0} = \mu_2 p_{n,1} + \lambda P_{n-1,0}$ |
| 0, m; m>0 | $(\lambda + \mu)P_{0,m} = \mu_2 p_{0,m-1} + \mu P_{1,m-1}$ |
| n,m; nm>0 | $(\lambda + \mu + \mu)P_{n,m} = \mu_2 P_{n,m+1} + \mu P_{n+1,m-1} + \lambda P_{n-1}$ |

The probability of n customers at server 1 is

$$P\{n \text{ at server } 1\} = \left(\frac{\lambda}{u_1}\right)^n \left(1-\frac{\lambda}{u_1}\right).$$

The probability of m customers at server 2 is

$$P\{m \text{ at server } 2\} = \left(\frac{\lambda}{u_2}\right)^m \left(1-\frac{\lambda}{u_2}\right)$$

If the number of customers at server 1 and 2 is independent, then

$$P_{n,m} = \left(\frac{\lambda}{u_1}\right)^n \left(1-\frac{\lambda}{u_1}\right) \left(\frac{\lambda}{u_2}\right)^m \left(1-\frac{\lambda}{u_2}\right)$$

The average number of customers in the system as L is given below:

$$L = \sum_{n,m} (n+m)P_{n,m}$$

$$= \sum_{n} n\left(\frac{\lambda}{M_1}\right)^n\left(1-\frac{\lambda}{M_1}\right) + \sum_{m} m\left(\frac{\lambda}{M_2}\right)^m\left(1-\frac{\lambda}{M_2}\right)$$

$$= \frac{\lambda}{u_1-\lambda} + \frac{\lambda}{u_2-\lambda}$$

The average time spent by a customer is W

$$W = \frac{L}{\lambda} = \frac{1}{u_1-\lambda} + \frac{1}{u_2-\lambda}$$

*b. Closed System*

The closed system assumes that no new customers enter, and existing ones never depart. Suppose there are *m* customers in a system of two servers. The stationary probability for the Markov chain by $\pi = (\pi_1, \ldots, \pi_k)$.

$$\pi_j = \sum_{i=1}^{k} \pi_i P_{ij}, \qquad \sum_{k}^{j=1} \pi_j = 1.$$

Denote the arriving rate at server j by $\lambda_m(j)$, $j = 1, \ldots, k$

$$\lambda_m(j) = \sum_{i=1}^{k} \lambda_m(i) P_{ij}$$

Denote the throughput rate as $\lambda_m(j) = \lambda_m \pi_j$, $j = 1, 2, \ldots, k$,

$$\text{where } \lambda_m = \sum_{k}^{j=1} \lambda_m(j)$$

The limiting probabilities are $P_m(n_1, n_2, \ldots, n_k) =$

$P\{n_j$ customers at server $j$, $j = 1, \ldots, k\}$

The limiting probabilities which satisfy the balance equation can be shown as

$$P_m(n_1, n_2, \ldots, n_k) = \begin{cases} K_m \sum_{j=1}^{k} (\lambda m(j)/M_j)^{nj} & \text{if } \sum_{i=1}^{k} nj=m \\ 0 & \text{otherwise} \end{cases}$$

$$\text{then } P_m(n_1, n_2, \ldots, n_k) = \begin{cases} C_m \prod_{j=1}^{k} (\pi_j/M_j)^{nj} & \text{if } \sum_{j=1}^{k} nj=m \\ 0 & \text{otherwise} \end{cases}$$

$$\text{where } C = \left[ \sum_{n_1, \ldots, n_k = \Sigma nj = m} \prod_{j=1}^{k} (\pi_j M_j)^{nj} \right]^{-1}$$

Now we determine the probability of customer being observed at server $l$

P{customer observes n at server $l$, $l = 1, \ldots, k$ | customer goes from $i$ to $j$}

$$= \frac{P\{\text{state is } (n, \ldots, n_{i+1}, \ldots, n_k), \text{ customer goes from } i \text{ to } j\}}{P\{\text{customer goes from } i \text{ to } j\}}$$

$$= \frac{P(n, \ldots, n_i+1, \ldots, n_i, \ldots, n_k)\mu_i P_{ij}}{\Sigma\, P_m(n_1, \ldots, n_i+1, \ldots, n_k)\mu_i P_{ij}}$$

$$= \frac{\pi_j \prod_{j=1}^{k} (\pi_j M_j)^{nj}}{K}$$

$$= C\prod_{j=1}^{k} (\pi_j/M_j)^{M_j}$$

In the arrival theorem, the closed network is a system with *m* customers, the system as seen by arrivals to server *j* is distributed as the stationary distribution in the same network system where there are only m–1 customers.

Let $L_m$ (j) = the average number of customer.

$W_m$ (j) = the average time a customer spends at server *j* for m customers.

$$W_m(j) = \frac{1 + E\,[\text{number at server } j \text{ as seen by an arrival}]}{u_j}$$

$$= \frac{1 + L_{m-1}(j)}{u_j}$$

For the m–1 customer, the arrival rate is $\lambda_{m-1}(j) = \lambda_{m-1}\,\pi_j$

Since the cost one m–1 customer pays one per unit time is

$$L_{m-1}(j) = \lambda_{m-1}\pi_j W_{m-1}(j)$$

then we get $W\,m(j) = \dfrac{1 + \lambda_{n-1}\pi_j W_{m-1}(j)}{u_j}$

Using the fact $\Sigma$ L (j) = m–1, we get

$$\lambda_{m-1} = \frac{m-1}{\sum_{i=1}^{k} \pi_i W_{m-1}(j)}$$

Finally we obtain the recursion

$$W\,m(j) = \frac{1}{u_j} + \frac{(m-1)\,\pi\,W\,(j)}{M\sum_{i=1}^{k} \pi_i W_{m-1}(j)}$$

This recursive approach is called MVA (Mean Value Analysis). [Ref. 6: p. 365-p. 374]

## C. HIERARCHICAL MODELING

Decomposition is a method of simplify the problem. Hierarchical modeling is the process of decomposing a large model into a number of smaller submodels. The individual solution of submodels is combined with the solution of the original model. The recombination is performed using a special type of service center called a flow equivalence service center (FESC). There are two key requirements in hierarchical modeling beyond the original need to define the levels of models. The first is to find a suitable structure for FESCs with a view to creating a single service center that can replace an entire subsystem. The second requirement is to evaluate models containing FESCs.

### 1. Flow Equivalence Service Center

The purpose of FESC is to mimic the behavior of the aggregate of the enclosed subsystem. This behavior, as viewed by the complementary subnetwork, is the flow of customers out of the aggregate and into the complement. An aggregate can be defined completely by a listing of its throughputs as a function of its possible customer populations.

Flow equivalence service centers are represented in queueing network models using load dependent service centers. This service center has a service rate which is a function of the customer population in its queue. FESC can be used to replace the detailed description of the aggregate in the model with little effect on the performance measures obtained. A FESC is formed by calculating throughputs X(n) of the aggregate as a function of the number n of customers in the aggregate.

## 2. Parameters and High-Level Models

The parameters required to specify an FESC are the load dependent service rates for each class as a function of the possible queue populations.

- Measurements may be possible to observe the subsystem that is to be aggregated, and to obtain measurements of its throughput as a function of the number of customers present.
- Queueing network models: The level $l$ FESC might be represented at level $l+1$ as a queueing network consisting of load independent service centers. This level $l+1$ model can be evaluated analytically, and the throughputs predicted from its solution will be used to set the service rates of the level $l$ FESC.
- Simulation: If some aspect of the aggregate makes it difficult to evaluate analytically, a simulation of the aggregate can be performed to obtain the required load dependent throughputs.
- Special purpose analytical methods. Models peculiar to a particular subsystem might be developed and solved analytically. The outputs of these models could be load dependent throughputs, which then would be used to define the FESC required in the next high level model.

Applying throughputs of FESCs, we can measure the performance of queueing network models at higher levels. The most obvious approach to evaluating high-level models is to apply analytical techniques. For separable high-level models, we can use the MVA (Mean Value Analysis) solution technique that allows the efficient evaluation of networks containing load dependent service centers. For non-seperable networks, we can use a modified MVA techniques.

The general analytic technique used to evaluate a closed, non-separable network is called global balance. The global balance solution technique involves creating and solving the large sets of linear equations that describe the behavior of these models. The implication of the rapid growth in the size of the state space with the size of the model is that global balance can be applied only to very small models.

The entire process is as follow. Isolate the I/O subsystem, evaluate the low-level model, create the high -level model, then evaluate the high-level model.

The global balance solution technique is based on analyzing transitions of the system from one "state" to another. Then define a state of a service center in the queueing network model to be an ordering of customers in its queue. There is a state space flow balance assumption that the rate of flow of the network into any state must equal the rate of flow of the network out of that state. The process of state space flow balance is to create the state space, calculate the state transition rates, create the flow balance equations, solve the flow balance equations, and compute performance measures. [Ref. 1: p. 152-p. 176]

# IV. SIMULATIONS FOR ANALYSIS OF LAN PERFORMANCE

## A. SIMULATION TOOL

SIMLAN II is a tool to analyze performance of LAN. It is designed to aid in LAN planning and analysis without programming. It consists of four main parts:

- LANGIN: Used to describe the LAN to be modeled.
- SIMLAN: the LAN simulation engine.
- LANPLOT: Used to plot/graph simulation statistics.
- LANAN: Post-processed LAN animation.

SIMLAN II can describe the configurations of LAN, STATION, GATEWAY, ROUTE, and SDF (Statistics Distribution Function). LAN technologies are classified into CSMA/CD, token ring, and token bus. The following CSMA/CD LAN implementations are available in SIMLAN II:

- IEEE 802.3 CSMA/CD 10BASE5.
- IEEE 802.3 Ethernet 10BASE5.
- IEEE 802.3 CSMA/CD 10BASE2.
- IEEE 802.3 CSMA/CD 1BASE5.
- IEEE 802.3 CSMA/CD STARLAN.
- IEEE 802.3 TOP.

The Token Ring LAN implementations available IN SIMLAN II are:

- IEEE 802.5 4Mb.
- IEEE 802.5 16Mb.

The Token Bus LAN implementations available in SIMLAN II are:

- IEEE 802.4 1Mb.
- IEEE 802.4 5Mb.
- IEEE 802.4 10Mb.

Stations can be defined as different types of terminals and servers. The parameters to Station are quantity, activities, files, processing time per cycle, storage capacity, kilobytes per sector, sector transfer time, and sector overhead time.

Gateway is the generic term for a repeater, bridge, or gateway. It is used for bi-directional interconnection of any two LANs. There is a set of I/O reformatting parameters for processing time. The processing time has a variable component, based on the number of bits to retransmit. A route is composed of a list of GATEWAY names followed by a destination Station. Associated with each GATEWAY in a route is an allowed LAN list.

The SDF (Statistical Distribution Function) holds the user-defined name of the distribution. SIMLANII supports the distributions of Beta, Erlang, Exponential, Gamma, IEEE Backoff, Log Normal, Normal, Pattern, Random Linear, Random Step, Triangle, Uniform. Each distribution has up to 8 attributes.

## B. SIMULATION MODELS

There are two models in this research which allow for multiple transaction classes. The first model is concerned with one server and various numbers of workstations (as Figure 20). The second model is concerned with two servers and various numbers of workstations (as Figure 21).

During the simulation, we set the PC as a workstation. PCs are simple function terminals. The number of server will be either one or two. The server's disk capacity is set to 100MB bits for sector 2 KB, and sector transfer time 200 microseconds. Sector overhead time is set to 10,000 microseconds.

There are three transaction classes which have different workload characteristics. Class 1 is a general access application. Class 2 is the e-mail. Class 3 is the file transfer. Each transaction class and its workload characteristics are shown in Table 1.

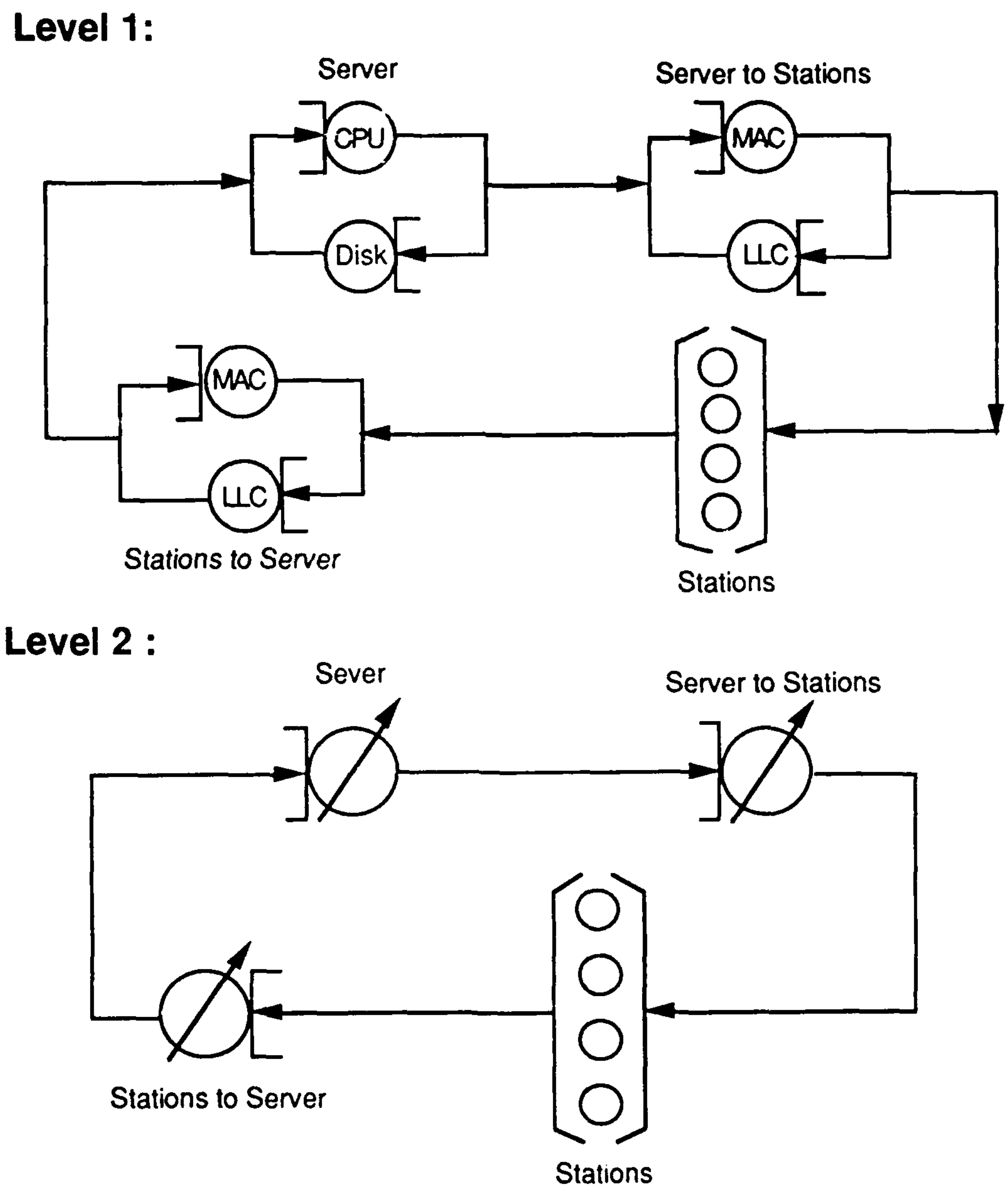



**Figure 20. One Server with Workstations in a Closed Queueing System**

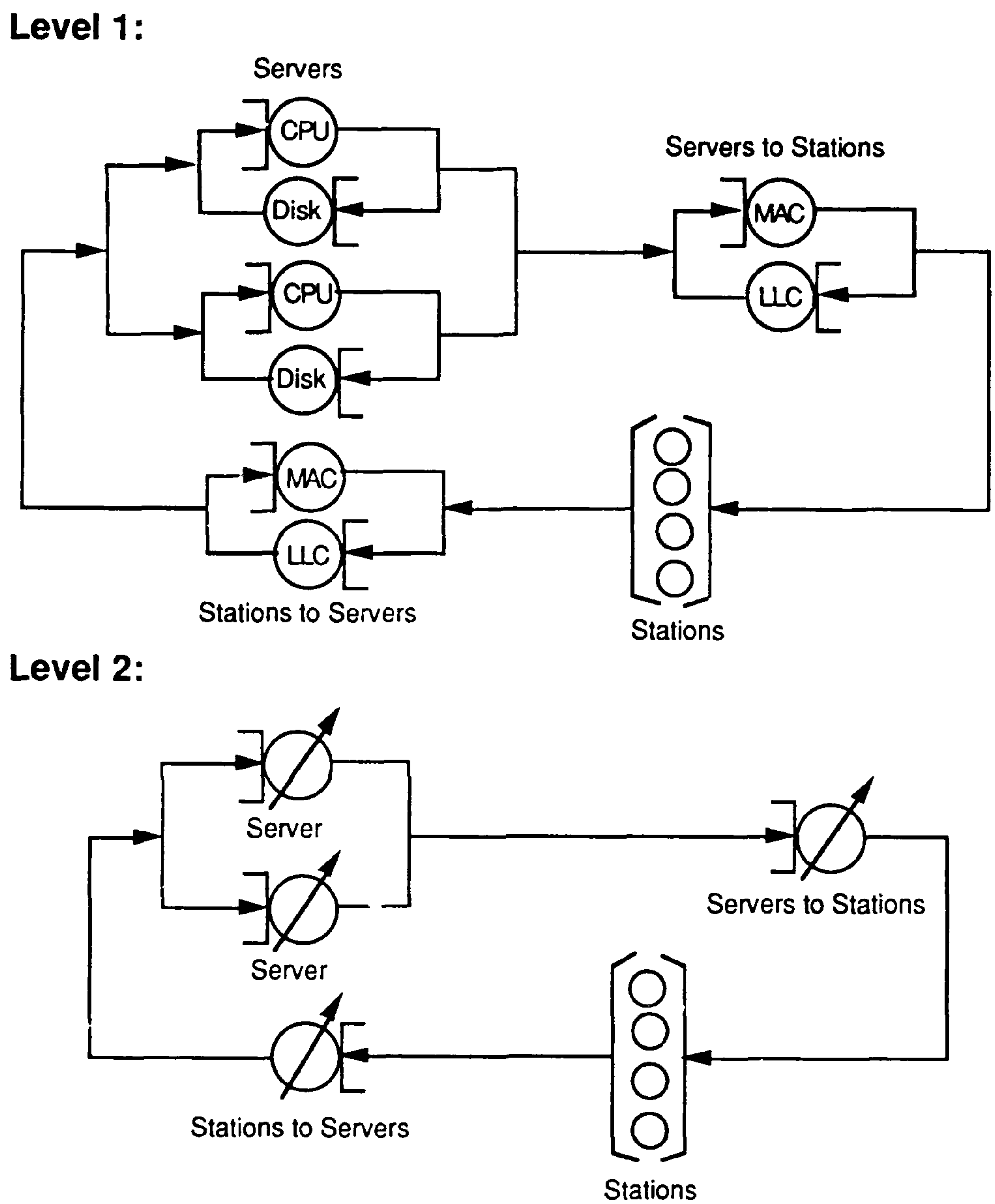



**Figure 21. Two Servers with Workstations in a Closed Queueing System**

**TABLE 1. TRANSACTION CLASSES AND THEIR WORKLOAD CHARACTERISTICS**

| CLASSES | ARRIVAL RATE | MESSAGE LENGTH | FILE LENGTH |
|---|---|---|---|
| 1 (PC 1) | 5 seconds | 1024 bits | 4096 bits |
| 2 (PC 2) | 10 seconds | 10240 bits | 1024 bits |
| 3 (PC 3) | 15 seconds | 1024 bits | 512000 bits |

We made 24 simulation runs for this research. The simulations are for the Ethernet (10BASE5), STARLAN, Token Ring of 4 Mbps, and Token Ring of 16 Mbps. Workstations include the PC 1, 2 and 3 for the transaction class 1, 2, and 3 respectively. The numbers of each PC will be 10, 20, or 30. The number of servers will be either one or two. The specifications are indicated as Table 2.

TABLE 2. SIMULATION CLASSIFICATION

| SIMULATION NO. | NETWORK TYPE | NO. OF PC1- PC3 | NO. OF SER.1-SER.3 |
|---|---|---|---|
| No. 1 | ETHERNET | 10 | 1 |
| No. 2 | ETHERNET | 20 | 1 |
| No. 3 | ETHERNET | 30 | 1 |
| No. 4 | ETHERNET | 10 | 2 |
| No. 5 | ETHERNET | 20 | 2 |
| No. 6 | ETHERNET | 30 | 2 |
| No. 7 | STARLAN | 10 | 1 |
| No. 8 | STARLAN | 20 | 1 |
| No. 9 | STARLAN | 30 | 1 |
| No. 10 | STARLAN | 10 | 2 |
| No. 11 | STARLAN | 20 | 2 |
| No. 12 | STARLAN | 30 | 2 |
| No. 13 | Token Ring (4 Mbps) | 10 | 1 |
| No. 14 | Token Ring (4 Mbps) | 20 | 1 |
| No. 15 | Token Ring (4 Mbps) | 30 | 1 |
| No. 16 | Token Ring (4 Mbps) | 10 | 2 |
| No. 17 | Token Ring (4 Mbps) | 20 | 2 |
| No. 18 | Token Ring (4 Mbps) | 30 | 2 |
| No. 19 | Token Ring (16 Mbps) | 10 | 1 |
| No. 20 | Token Ring (16 Mbps) | 20 | 1 |
| No. 21 | Token Ring (16 Mbps) | 30 | 1 |
| No. 22 | Token Ring (16 Mbps) | 10 | 2 |
| No. 23 | Token Ring (16 Mbps) | 20 | 2 |
| No. 24 | Token Ring (16 Mbps) | 30 | 2 |

## C. SIMULATION RESULTS

The results of simulations are classified as below:

- LAN utilization with one and two servers (Tables 3-4 and Figures 22-23).
- The number of transactions completed during the simulation period with one or two servers to each class (Tables 5-6 and Figures 24-25).

- AVG, MAX STD DEV request delay with one or two servers (as Tables 7-12 and Figures 26-31)
- AVG, STD DEV delivery time for transaction class 1 with one or two servers: from PC to Server (Tables 13-16 and Figures 32-35).
- AVG, STD DEV delivery time for transaction class 1 with one or two servers: from Server to PC (Tables 17-20 and Figures 36-39).
- AVG, STD DEV delivery time for transaction class 2 with one or two servers: from PC to Server (Tables 21-24 and Figures 40-43).
- AVG, STD DEV delivery time for transaction class 2 with one or two servers: from Server to PC (Tables 25-28 and Figures 44-47).
- AVG, STD DEV delivery time for transaction class 3 with one or two servers: from PC to Server (Tables 29-32 and Figures 48-51).
- AVG, STD DEV delivery time for transaction class 3 with one or two servers: from Server to PC (Tables 33-36 and Figures 52-55).

During the simulation on STARLAN with two servers and 30 PCs for three transaction classes, SIMLAN II failed with the message "insufficient memory." Therefore, we could not obtain the results from this simulation run. For each simulation, two pages of printout from the SIMLAN were chosen and put in Appendix B.

From Tables 3, 4 and Figure 22, 23, we observe that LAN utilization increases as the number of servers and PCs increases. Generally, Token ring (16 Mbps) shows the lowest LAN utilization.

**TABLE 3. LAN UTILIZATION WITH ONE SERVER**

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 7.078% | 18.217% | 5.448% | 3.629% |
| 20 PCs | 8.299% | 19.612% | 6.095% | 5.081% |
| 30 PCs | 10.366% | * | 7.176% | 7.638% |

* : No results for "Insufficient Memory"

TABLE 4. LAN UTILIZATION WITH TWO SERVERS

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 8.621% | 25.213% | 6.744% | 3.884% |
| 20 PCs | 12.941% | 33.215% | 9.983% | 6.225% |
| 30 PCs | 15.488% | 37.301% | 11.489% | 9.037% |

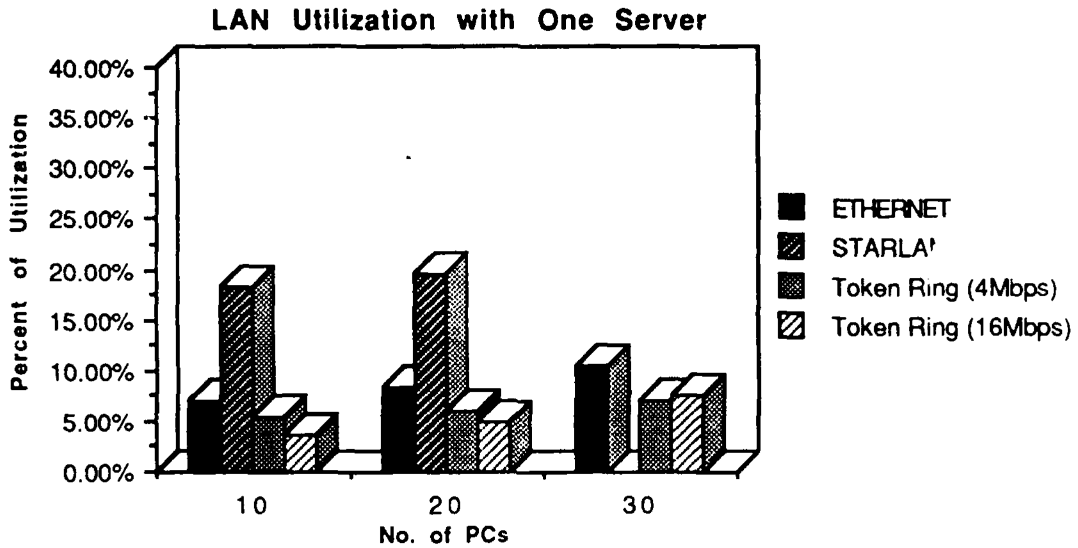



Figure 22. LAN Utilization with One Server

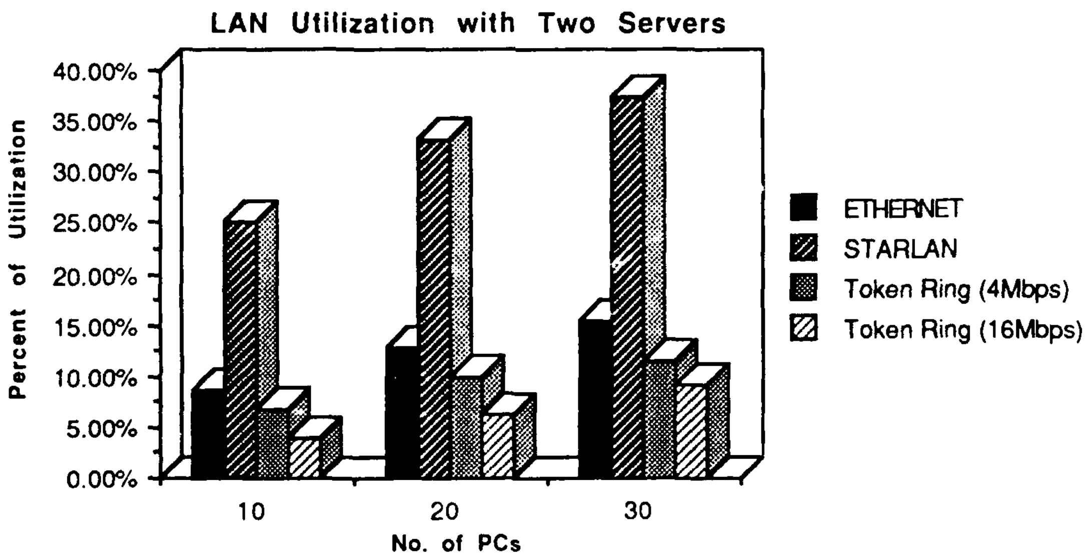



Figure 23. LAN Utilization with Two Servers

It is obvious from Tables 5-6 and Figure 24-25 that the number of completed transfers increases as the number of PCs increase but does very little as another server is added.

**TABLE 5. THE NUMBER OF COMPLETED TRANSFERS WITH ONE SERVER IN THE SIMULATION PERIOD**

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 205 | 204 | 205 | 206 |
| 20 PCs | 333 | 330 | 334 | 335 |
| 30 PCs | 563 | * | 565 | 564 |

* : No results for "Insufficient Memory"

**TABLE 6. THE NUMBER OF COMPLETED TRANSFERS WITH TWO SERVERS IN THE SIMULATION PERIOD**

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 208 | 208 | 208 | 208 |
| 20 PCs | 343 | 338 | 345 | 344 |
| 30 PCs | 573 | 561 | 573 | 575 |

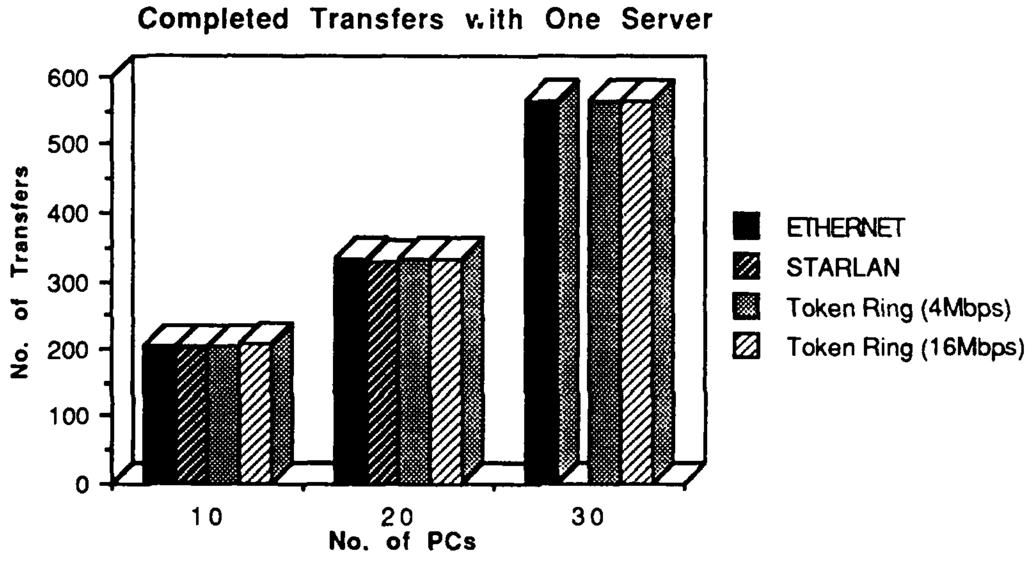



Figure 24. The Number of Completed Transfers with One Server in The Simulation Period

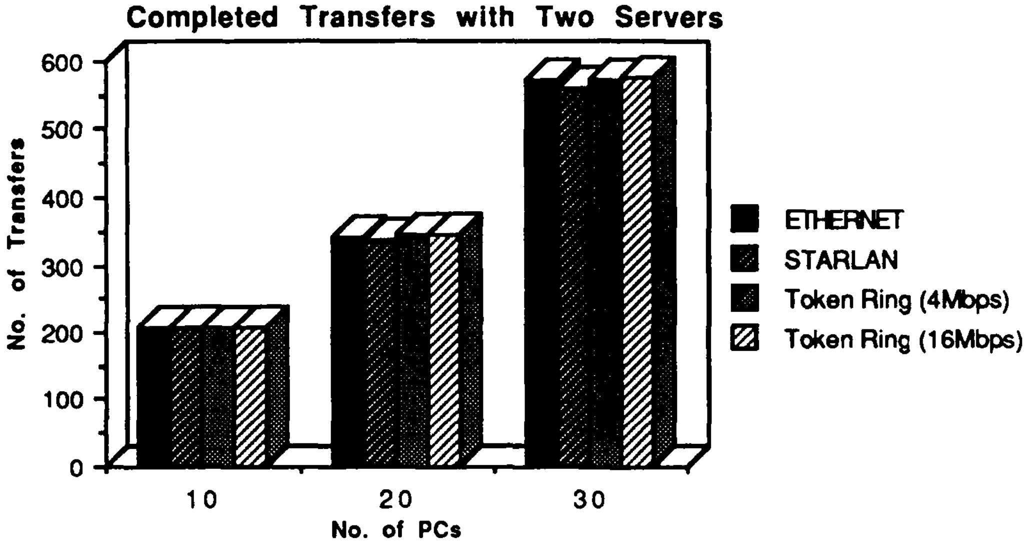



**Figure 25. The Number of Completed Transfers with Two Servers in The Simulation Period**

In Tables 7-12 and Figure 26-31, the Token Ring (16Mbps) gets the lowest AVG, MAX and STD DEV of request delay. All request delays increase as another server is added.

TABLE 7. AVG REQUEST DELAY WITH ONE SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 50151.580 | 84328.809 | 2269.595 | 172.590 |
| 20 PCs | 56127.702 | 94656.048 | 1729.197 | 74.277 |
| 30 PCs | 25478.260 | * | 2322.694 | 668.968 |

* : No results for "Insufficient Memory"

TABLE 8. AVG REQUEST DELAY WITH TWO SERVERS

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 64571.787 | 133661.365 | 3570.050 | 278.307 |
| 20 PCs | 41960.417 | 94347.951 | 2312.904 | 763.850 |
| 30 PCs | 36463.087 | 95193.383 | 5167.167 | 850.525 |

TABLE 9. MAX REQUEST DELAY WITH ONE SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 143195.535 | 466802.274 | 107250.075 | 23142.154 |
| 20 PCs | 149720.121 | 501125.233 | 108435.671 | 4256.092 |
| 30 PCs | 152769.045 | * | 133207.065 | 39203.551 |

* : No results for "Insufficient Memory"

TABLE 10. MAX REQUEST DELAY WITH TWO SERVERS

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 154086.400 | 520656.000 | 128418.750 | 35874.964 |
| 20 PCs | 149099.162 | 490183.915 | 120575.453 | 40376.681 |
| 30 PCs | 154348.800 | 521950.959 | 133207.065 | 39203.551 |

TABLE 11. STD DEV REQUEST DELAY WITH ONE SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 59763.925 | 134307.195 | 13267.284 | 1643.716 |
| 20 PCs | 63061.845 | 154340.568 | 11297.425 | 429.632 |
| 30 PCs | 47855.382 | * | 14786.354 | 3887.437 |

* : No results for "Insufficient Memory"

TABLE 12. STD DEV REQUEST DELAY WITH TWO SERVERS

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 61746.608 | 172582.668 | 18200.139 | 2629.222 |
| 20 PCs | 53637.528 | 152638.724 | 13731.974 | 4568.426 |
| 30 PCs | 55531.855 | 171544.508 | 22564.794 | 4570.274 |

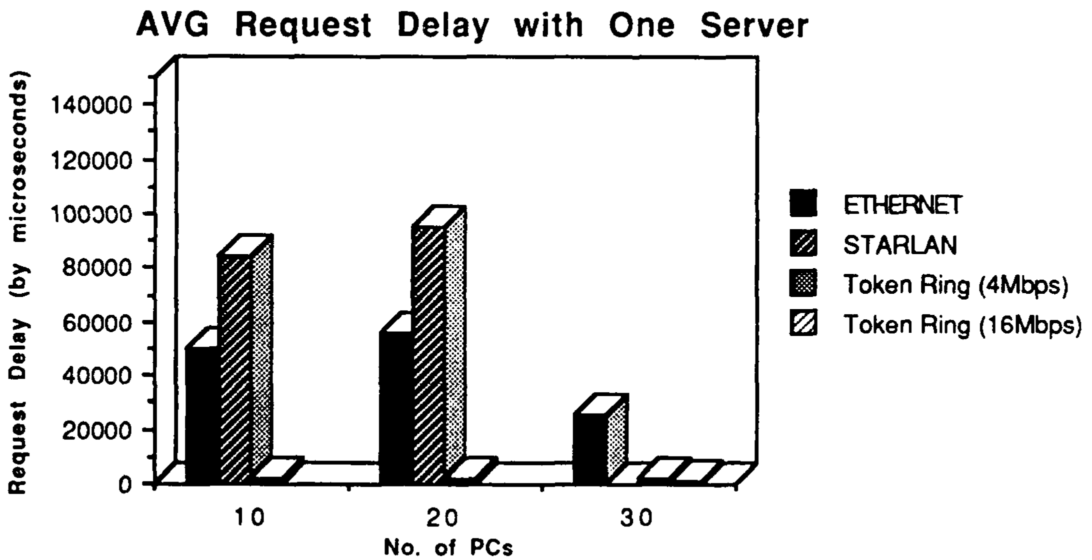



Figure 26. AVG Request Delay with One Server

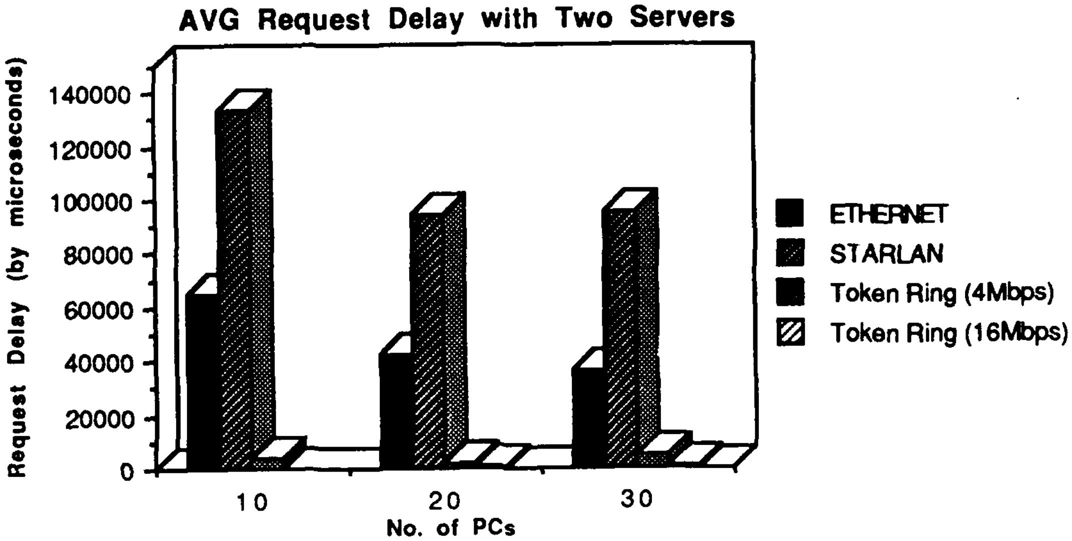



Figure 27. AVG Request Delay with Two Servers

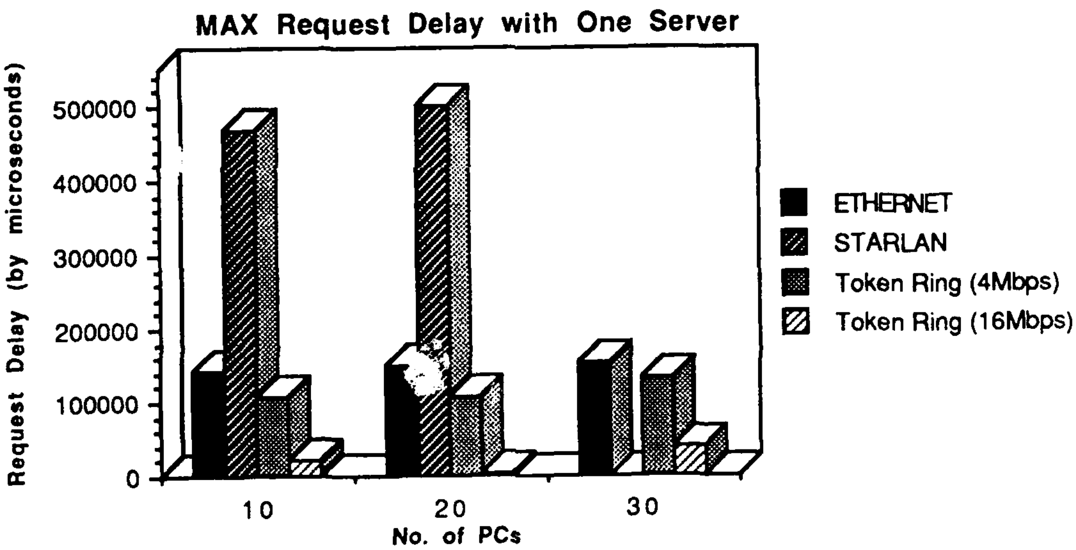



Figure 28. MAX Request Delay with One Server

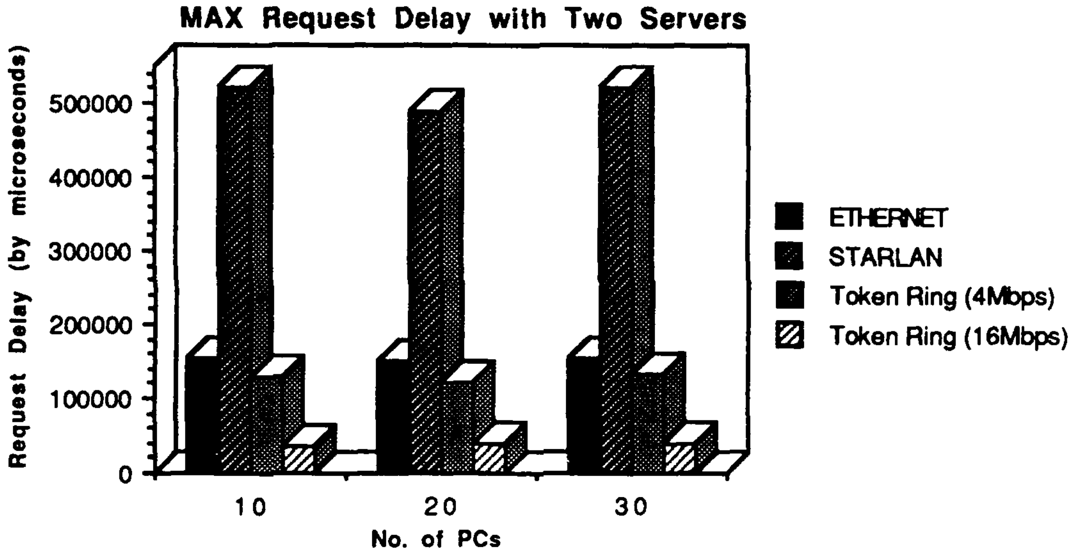



Figure 29. MAX Request Delay with Two Servers

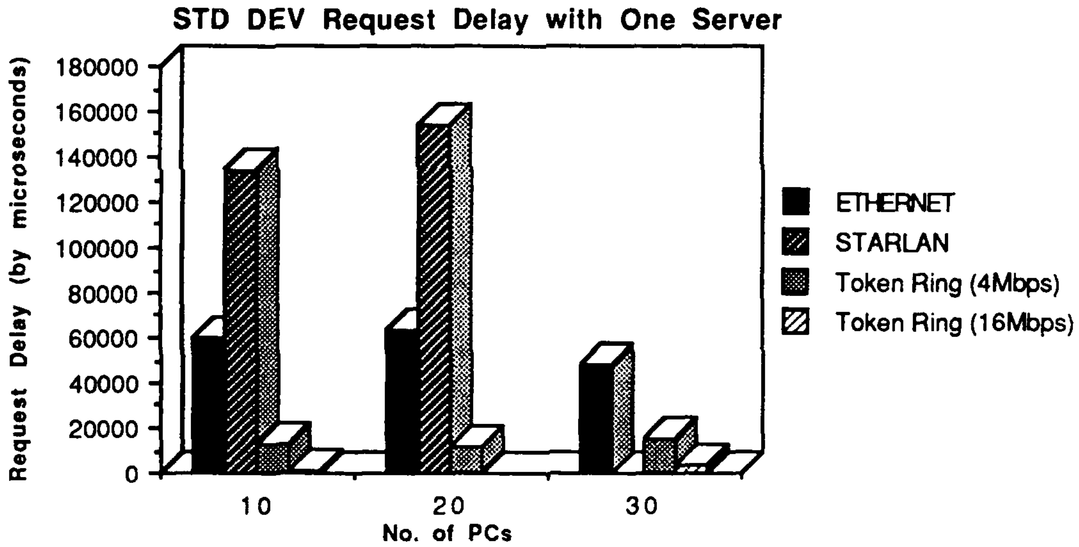



Figure 30. STD DEV Request Delay with One Server

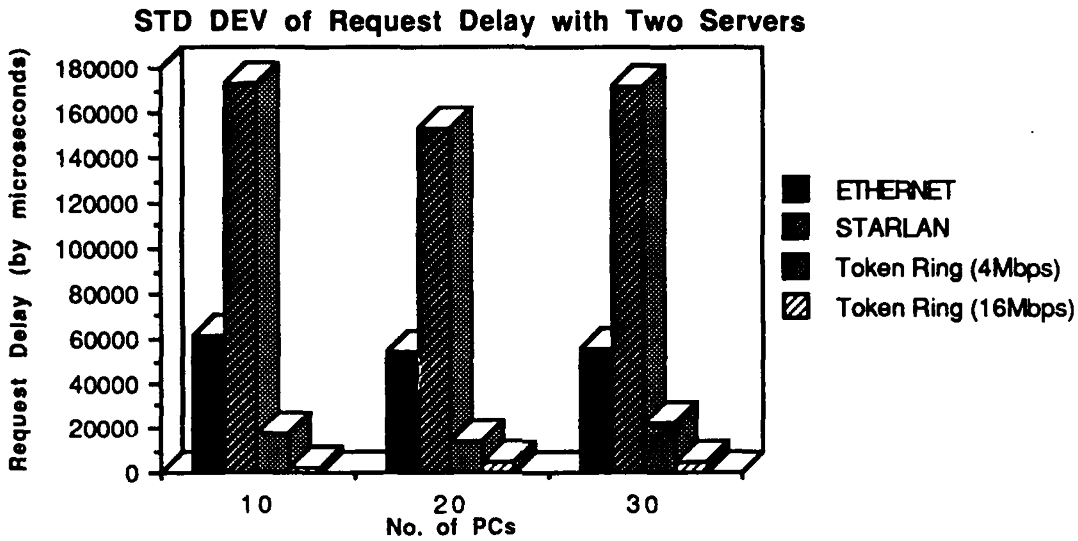



Figure 31. STD DEV of Request Delay with Two Servers

In Tables 13 to 20 and Figures 32-55, the AVG and STD DEV delivery time for three class transactions are shown. MAX, MIN delivery time and incomplete transfers are summarized in Appendix B as a reference. In general, the AVG and STD DEV delivery times increase as another server is added.

In Tables 13-16 and Figures 32-35, the delivery time decreases only for the Ethernet and Token Ring (4Mbps) as another server is added.

TABLE 13. AVG DELIVERY TIME FOR TRANSACTION CLASS 1 WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 11867.968 | 29180.839 | 6766.032 | 3741.952 |
| 20 PCs | 9062.533 | 43895.033 | 5300.261 | 3337.054 |
| 30 PCs | 6464.145 | * | 3599.891 | 4120.618 |

* : No results for "Insufficient Memory"

TABLE 14. AVG DELIVERY TIME FOR TRANSACTION CLASS 1 WITH TWO SERVERS: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 6837.677 | 36109.210 | 6772.984 | 3520.194 |
| 20 PCs | 5200.804 | 94155.044 | 4639.174 | 3894.391 |
| 30 PCs | 16508.058 | 133087.262 | 7602.942 | 4315.017 |

TABLE 15. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 1 WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 32615.725 | 87634.480 | 20148.135 | 2930.446 |
| 20 PCs | 27131.115 | 119605.127 | 17372.401 | 462.513 |
| 30 PCs | 19969.073 | * | 14566.379 | 4305.052 |

* : No results for "Insufficient Memory"

TABLE 16. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 1 WITH TWO SERVERS: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 18865.552 | 101926.895 | 22954.570 | 1557.111 |
| 20 PCs | 14724.276 | 160287.560 | 16024.072 | 4336.903 |
| 30 PCs | 42429.481 | 249857.496 | 23574.016 | 4971.324 |

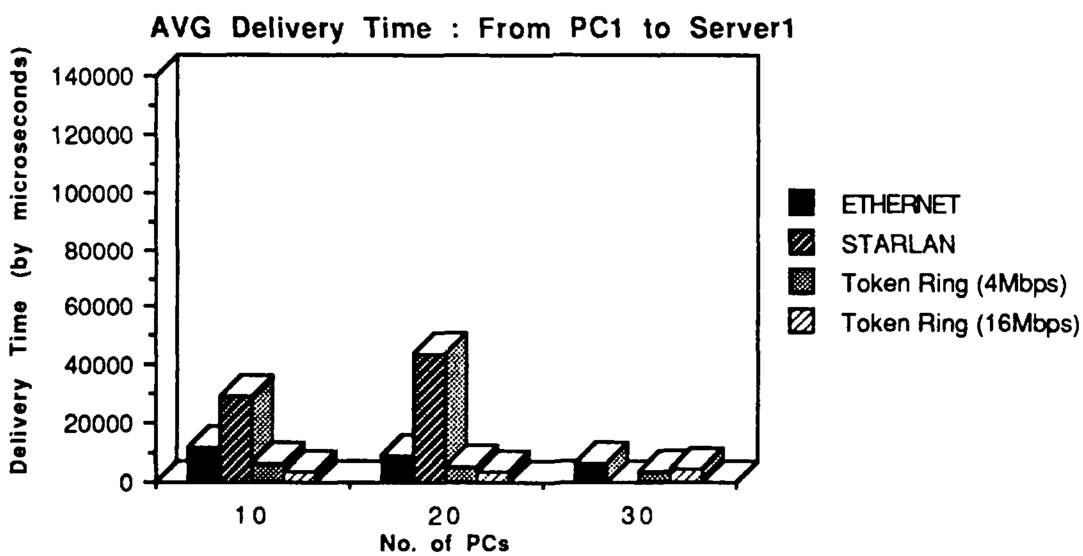



Figure 32. AVG Delivery Time for Transaction Class 1 with One Server: From PC to Server

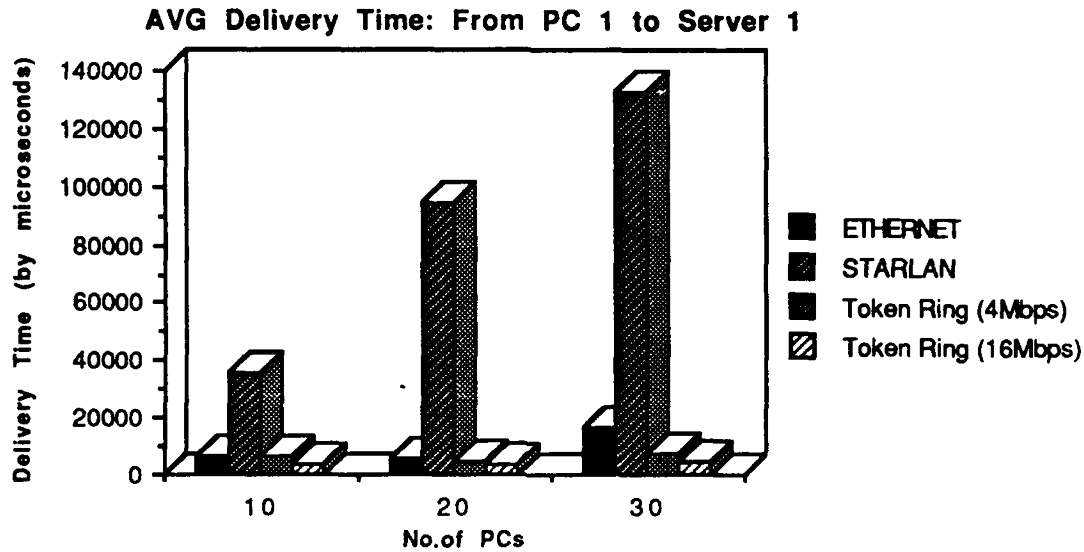



Figure 33. AVG Delivery Time for Transaction Class 1 with Two Servers: From PC to Server

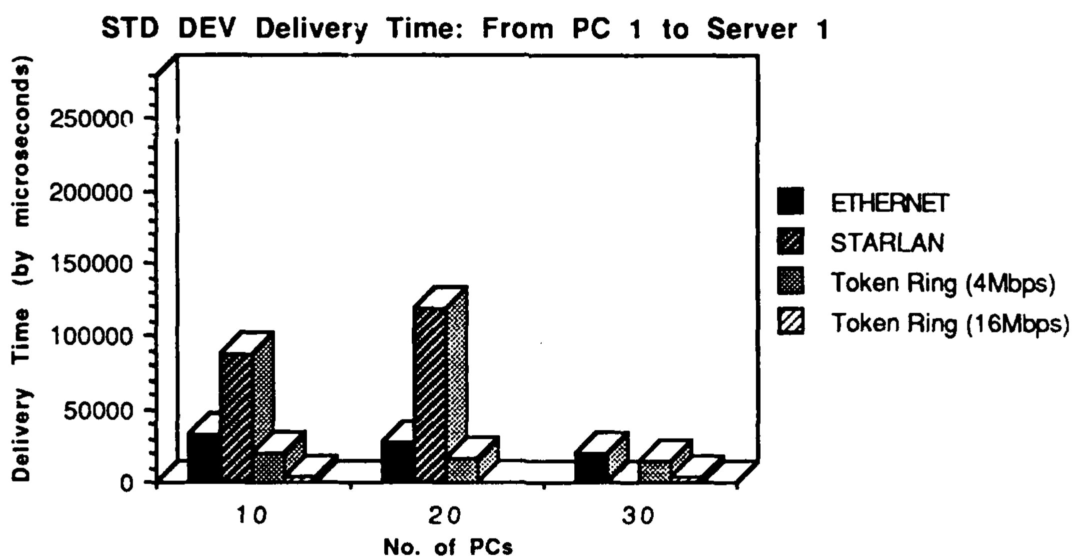



Figure 34. STD DEV Delivery Time for Transaction Class 1 with One Server: From PC to Server

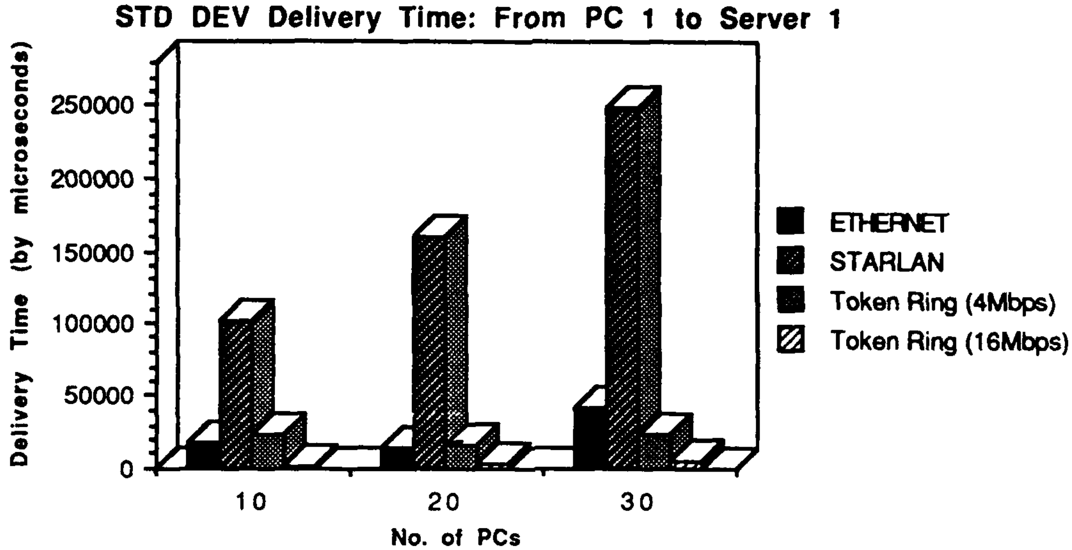



Figure 35. STD DEV Delivery Time for Transaction Class 1 with Two Servers: From PC to Server

In Tables 17-20 and Figures 36-39, the delivery time decreases only for the StarLAN with 20 PCs and Token Ring (4Mbps) with 10 PCs as another server is added.

TABLE 17. AVG DELIVERY TIME FOR TRANSACTION CLASS 1 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2938.081 | 4358.387 | 3423.065 | 3518.484 |
| 20 PCs | 6160.556 | 10314.278 | 1828.066 | 3514.385 |
| 30 PCs | 4624.538 | * | 3693.052 | 3962.653 |

* : No results for "Insufficient Memory"

TABLE 18. AVG DELIVERY TIME FOR TRANSACTION CLASS 1 WITH TWO SERVERS: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 5577.210 | 4606.726 | 1824.000 | 4100.468 |
| 20 PCs | 7361.231 | 5031.711 | 3081.890 | 4750.187 |
| 30 PCs | 8952.636 | 48672.661 | 7597.08. | 4411.497 |

TABLE 19. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 1 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 789.253 | 237.331 | 12470.925 | 354.374 |
| 20 PCs | 21884.704 | 53077.658 | 38.573 | 453.046 |
| 30 PCs | 15823.597 | * | 14012.552 | 3366.595 |

* : No results for "Insufficient Memory"

TABLE 20. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 1 WITH TWO SERVERS: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 19589.863 | 1838.676 | 0.000 | 4524.470 |
| 20 PCs | 24604.564 | 3734.011 | 11779.202 | 5299.492 |
| 30 PCs | 27626.247 | 167433.518 | 26273.638 | 5023.771 |

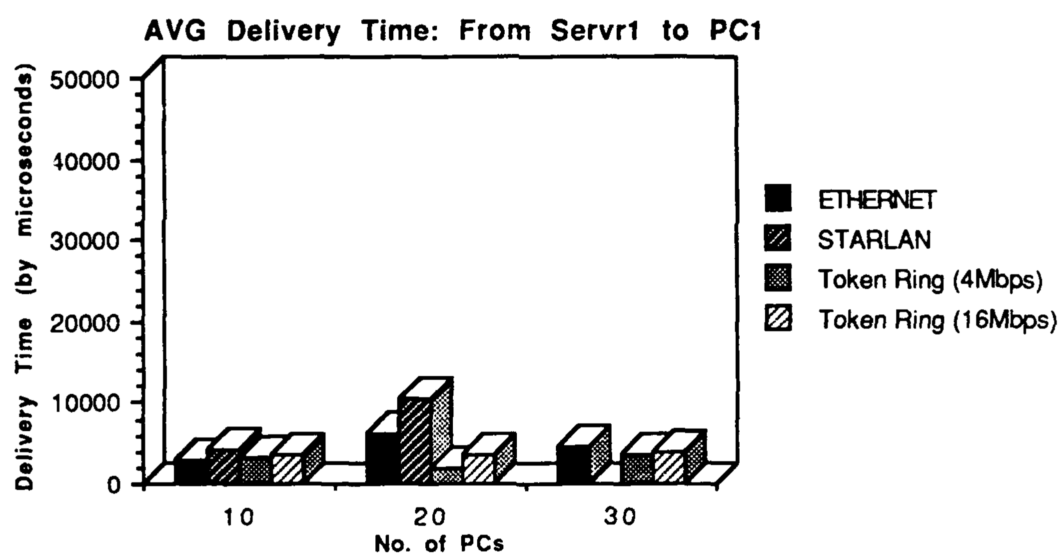



Figure 36. AVG Delivery Time for Transaction Class 1 with One Server: From Server to PC

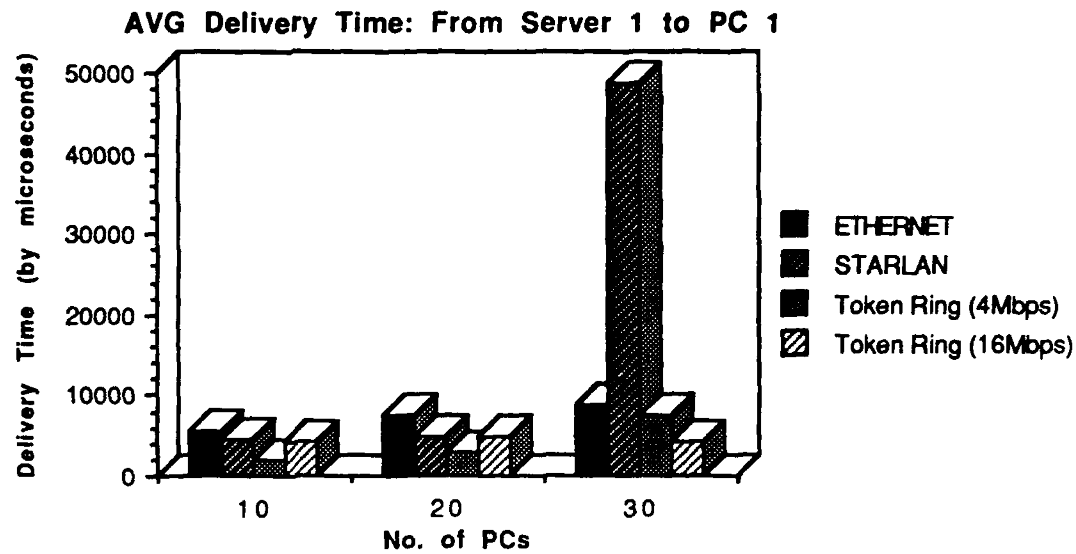



Figure 37. AVG Delivery Time for Transaction Class 1 with Two Servers: From Server to PC

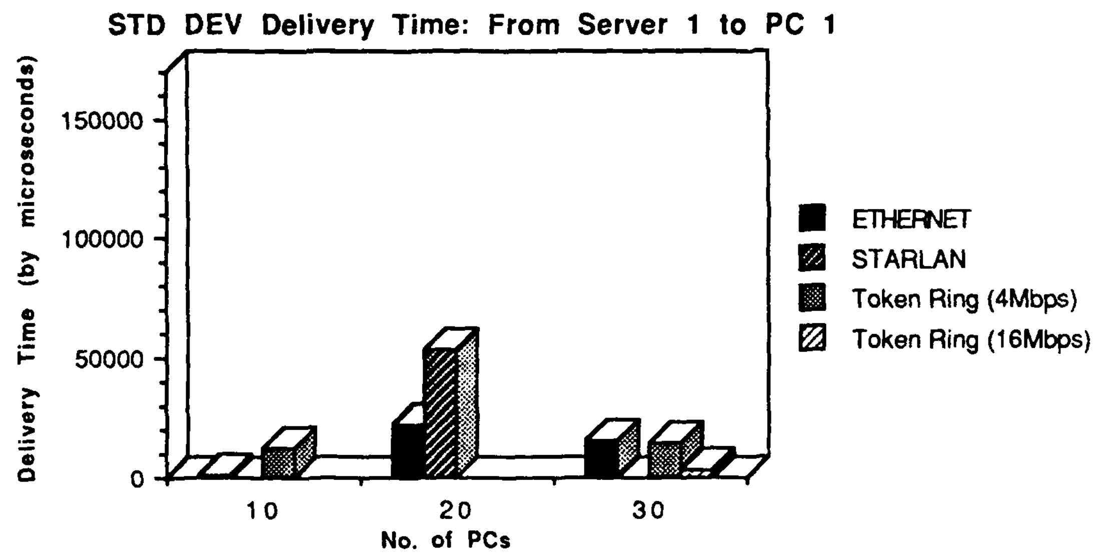



Figure 38. STD DEV Delivery Time for Transaction Class 1 with One Server: From Server to

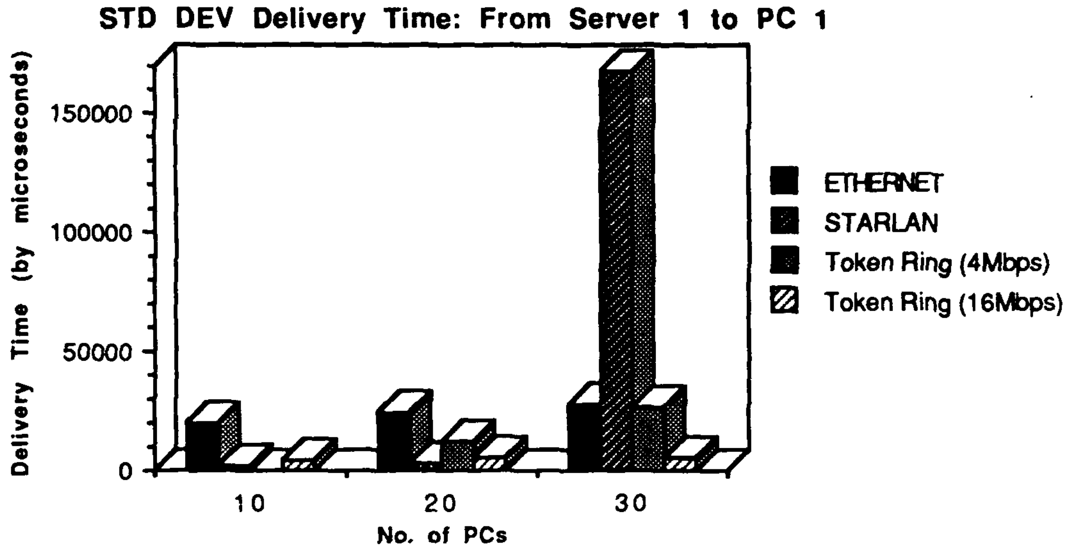



**Figure 39. STD DEV Delivery Time for Transaction Class 1 with Two Servers: From Server to PC**

In Tables 21-24 and Figures 40-43, the AVG and *STD DEV* delivery time decrease only for the Ethernet and StarLAN with 10 PCs as another server is added.

**TABLE 21. AVG DELIVERY TIME FOR TRANSACTION CLASS 2 WITH ONE SERVER: FROM PC TO SERVER**

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 14649.963 | 54493.667 | 4596.148 | 4010.889 |
| 20 PCs | 10058.760 | 48208.120 | 5096.680 | 3987.840 |
| 30 PCs | 8508.333 | * | 5363.213 | 4443.013 |

* : No results for "Insufficient Memory"

**TABLE 22. AVG DELIVERY TIME FOR TRANSACTION CLASS 2 WITH TWO SERVERS: FROM PC TO SERVER**

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 5130.148 | 39051.963 | 7352.926 | 4010.889 |
| 20 PCs | 12464.960 | 87659.600 | 10000.320 | 3987.840 |
| 30 PCs | 16288.587 | 121827.827 | 7798.347 | 4443.013 |

TABLE 23. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 2 WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 34897.673 | 115019.163 | 5194.851 | 820.793 |
| 20 PCs | 25881.664 | 88656.646 | 11040.894 | 769.471 |
| 30 PCs | 23503.999 | * | 13422.064 | 4635.304 |

* : No results for "Insufficient Memory"

TABLE 24. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 2 WITH TWO SERVERS: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 3487.968 | 83137.008 | 16693.331 | 820.973 |
| 20 PCs | 27871.870 | 136761.852 | 23699.558 | 769.471 |
| 30 PCs | 37265.818 | 199678.313 | 18443.917 | 4635.304 |

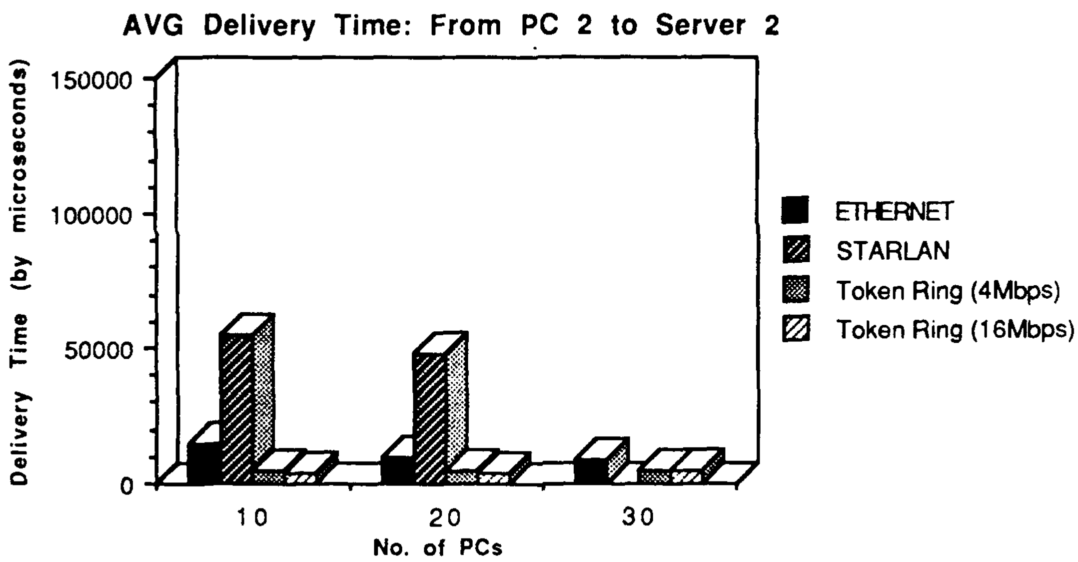



Figure 40. AVG Delivery Time for Transaction Class 2 with One Server: From PC to Server

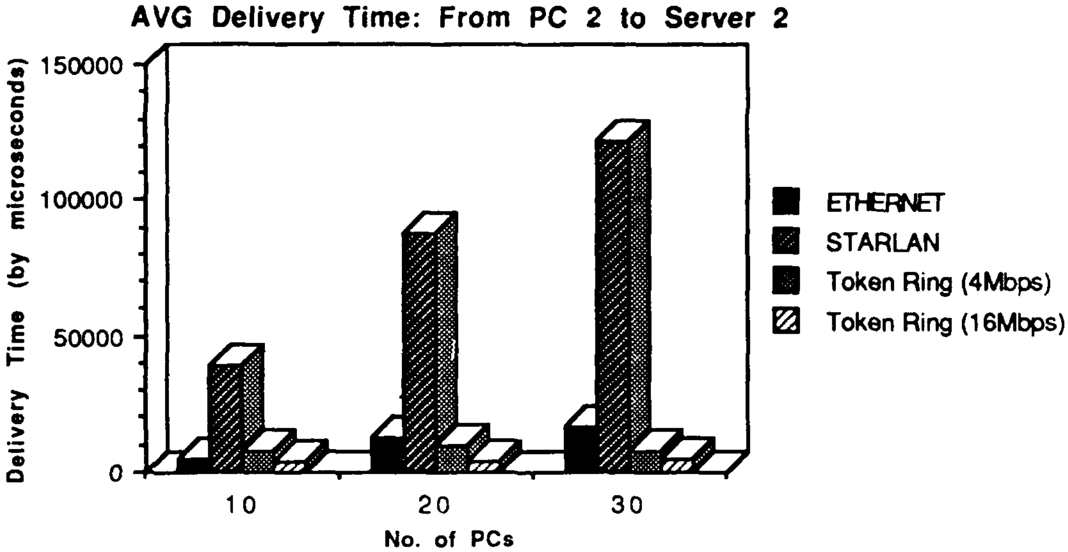



Figure 41. AVG Delivery Time for Transaction Class 2 with Two Servers: From PC to Server

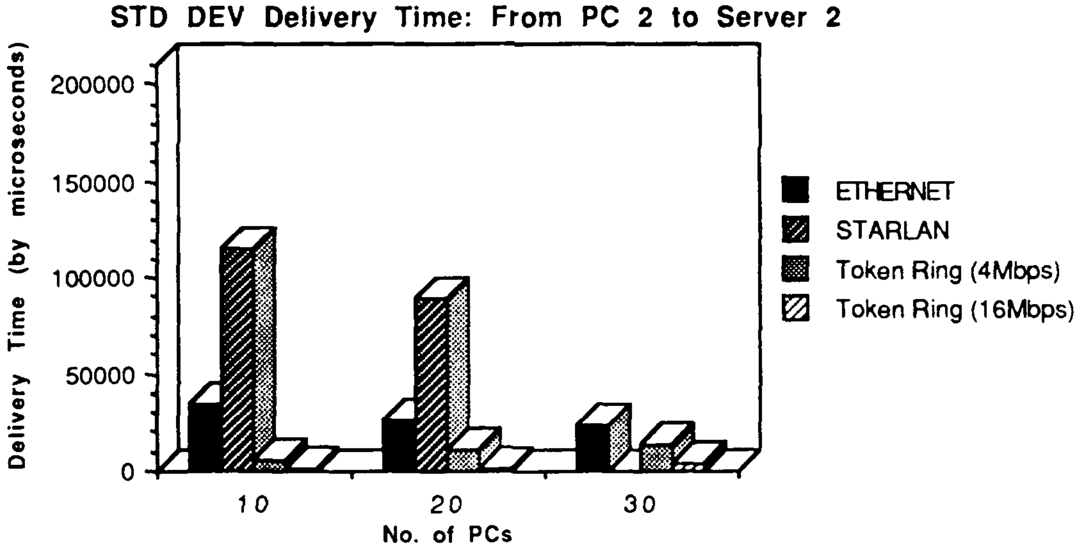



Figure 42. STD DEV Delivery Time for Transaction Class 2 with One Server: From PC to Server

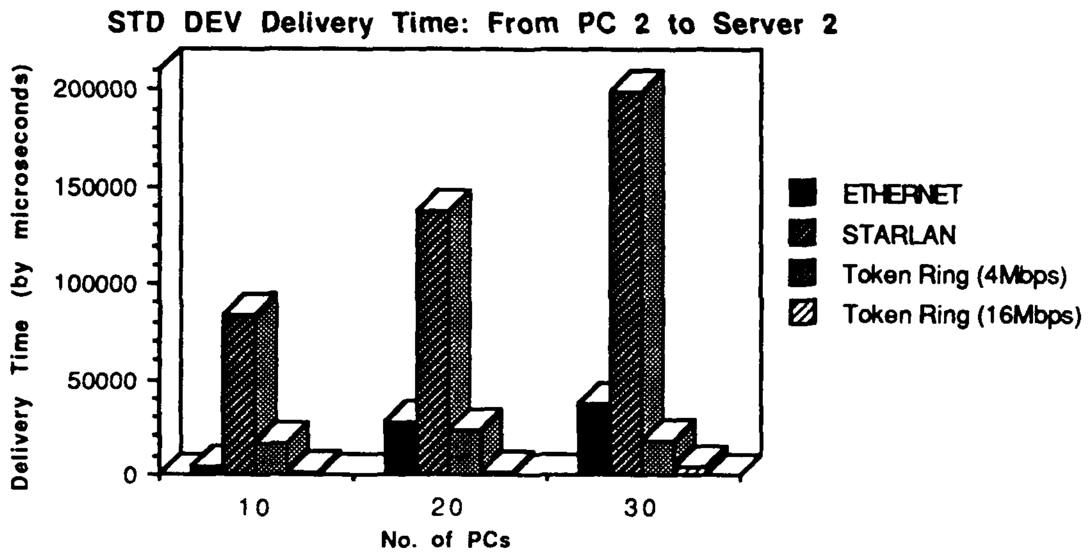



Figure 43. STD DEV Delivery Time for Transaction Class 2 with Two Servers: From PC to Server

In Tables 25-28 and Figures 44-47, the AVG and STD DEV delivery times decrease only for the StarLAN with 10 PCs as another server is added.

TABLE 25. AVG DELIVERY TIME FOR TRANSACTION CLASS 2 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2643.222 | 1411.333 | 1056.000 | 3263.000 |
| 20 PCs | 2637.700 | 1723.260 | 1247.620 | 3333.120 |
| 30 PCs | 4606.760 | * | 1209.413 | 31291.000 |

* : No results for "Insufficient Memory"

TABLE 26. AVG DELIVERY TIME FOR TRANSACTION CLASS 2 WITH TWO SERVERS: FROM SERVFR TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2502.000 | 1256.000 | 1056.000 | 3263.000 |
| 20 PCs | 2762.340 | 1543.020 | 1216.700 | 4093.900 |
| 30 PCs | 12509.600 | 49128.907 | 11864.000 | 3736.480 |

## TABLE 27. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 2 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 720.095 | 792.048 | 0.000 | 0.000 |
| 20 PCs | 625.415 | 2295.834 | 1141.187 | 434.220 |
| 30 PCs | 16290.853 | * | 1240.179 | 3247.973 |

* : No results for "Insufficient Memory"

## TABLE 28. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 2 WITH TWO SERVERS: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 0.000 | 0.000 | 0.000 | 0.000 |
| 20 PCs | 913.501 | 1509.253 | 1124.900 | 5333.140 |
| 30 PCs | 36728.251 | 159699.991 | 1240.145 | 3247.973 |

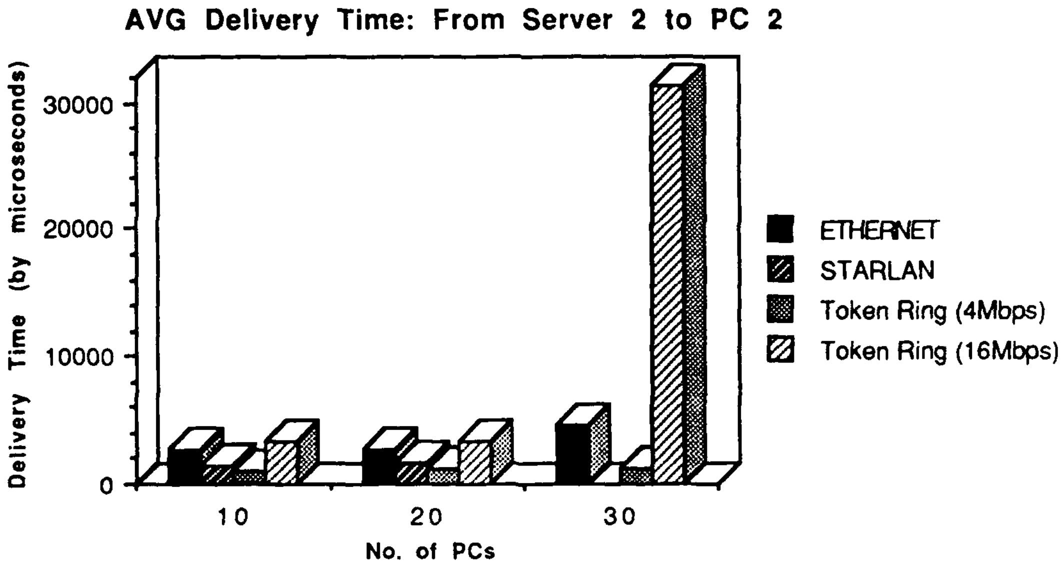



Figure 44. AVG Delivery Time for Transaction Class 2 with One Server: From Server to PC

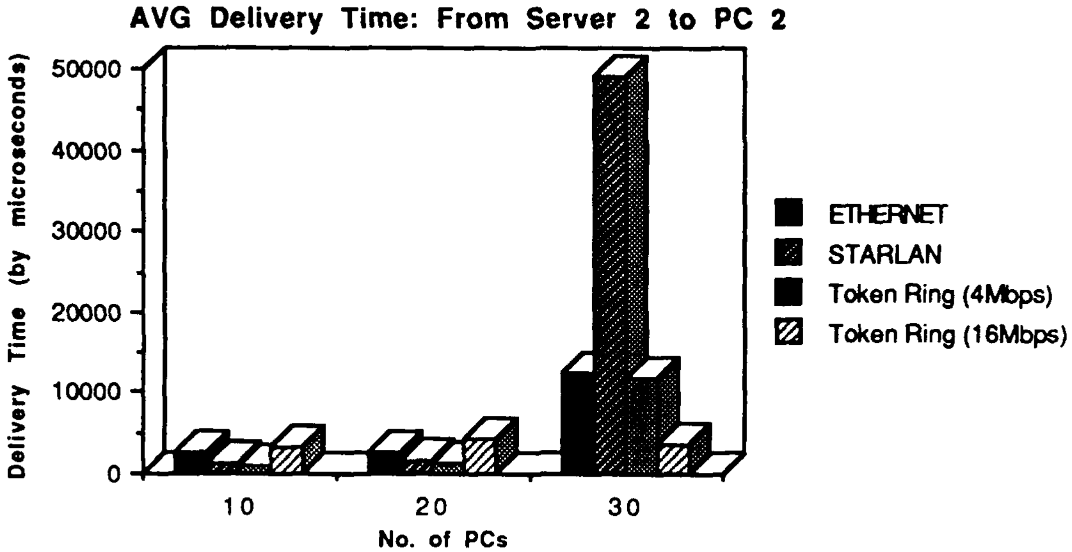



Figure 45. AVG Delivery Time for Transaction Class 2 with Two Servers: From Server to PC

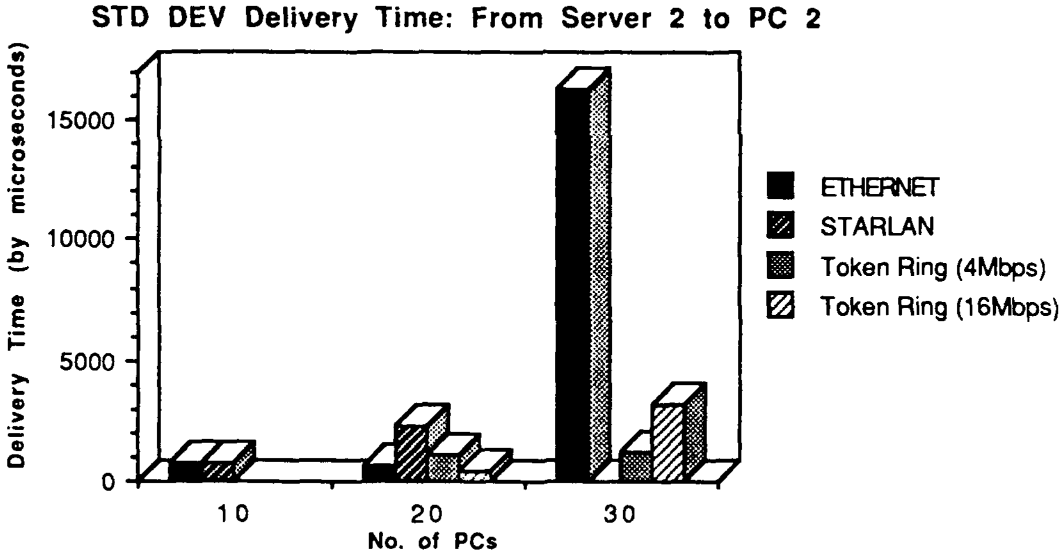



Figure 46. STD DEV Delivery Time for Transaction Class 2 with One Server: From Server to PC

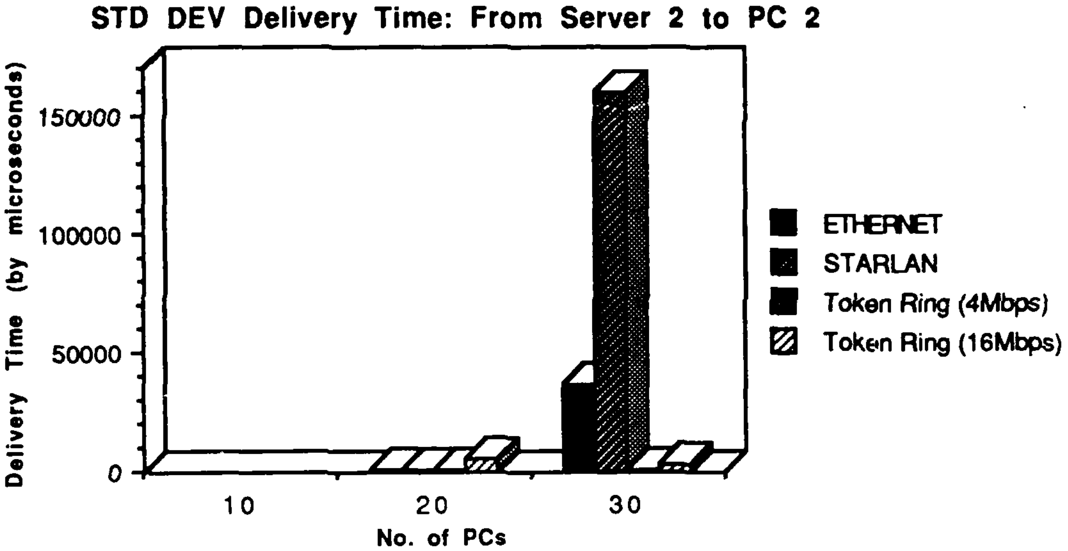



Figure 47. STD DEV Delivery Time for Transaction Class 2 with Two Servers: From Server to PC

In Tables 29-32 and Figures 48-51, the AVG and STD DEV delivery time decrease only for the Token Ring (4Mbps) with 20 PCs as another server is added.

TABLE 29. AVG DELIVERY TIME FOR TRANSACTION CLASS 3 WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2815.647 | 33822.294 | 1102.647 | 3423.647 |
| 20 PCs | 2502.780 | 78825.195 | 3388.780 | 3331.585 |
| 30 PCs | 541.316 | * | 7144.965 | 4158.860 |

* : No results for "Insufficient Memory"

TABLE 30. AVG DELIVERY TIME FOR TRANSACTION CLASS 3 WITH TWO SERVERS: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 24795.353 | 86318.647 | 11315.588 | 3423.647 |
| 20 PCs | 15565.732 | 78694.854 | 1409.829 | 4212.293 |
| 30 PCs | 8085.702 | 127698.474 | 8947.351 | 4167.158 |

TABLE 31. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 3 WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 916.435 | 62535.860 | 232.134 | 591.376 |
| 20 PCs | 85.882 | 152679.908 | 14072.068 | 320.698 |
| 30 PCs | 316.486 | * | 25851.272 | 4009.077 |

* : No results for "Insufficient Memory"

TABLE 32. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 3 WITH TWO SERVERS: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 72066.550 | 154582.794 | 25153.387 | 591.376 |
| 20 PCs | 36831.944 | 150929.907 | 1992.127 | 5840.285 |
| 30 PCs | 28709.959 | 197244.378 | 28876.386 | 4007.741 |

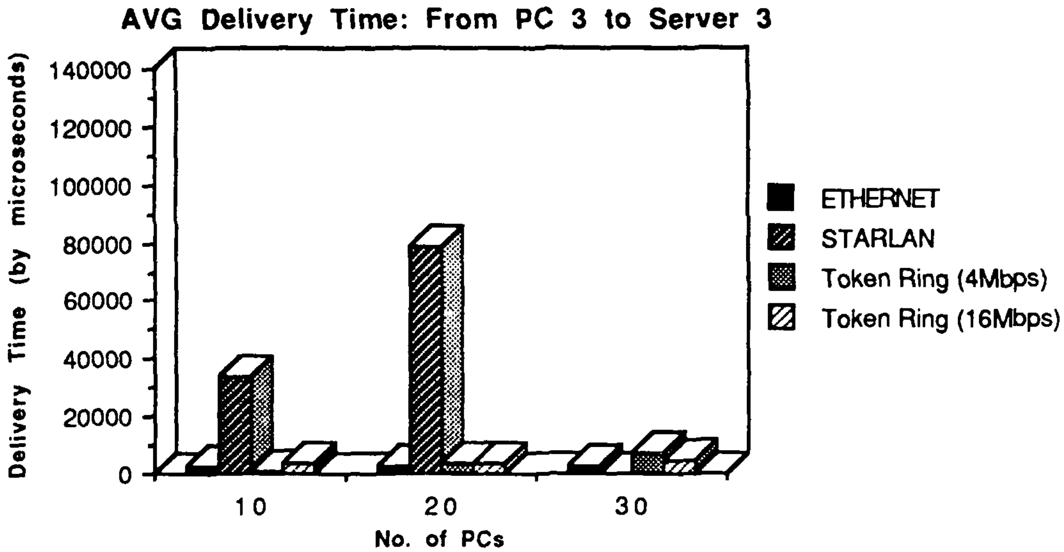



Figure 48. AVG Delivery Time for Transaction Class 3 with One Server: From PC to Server

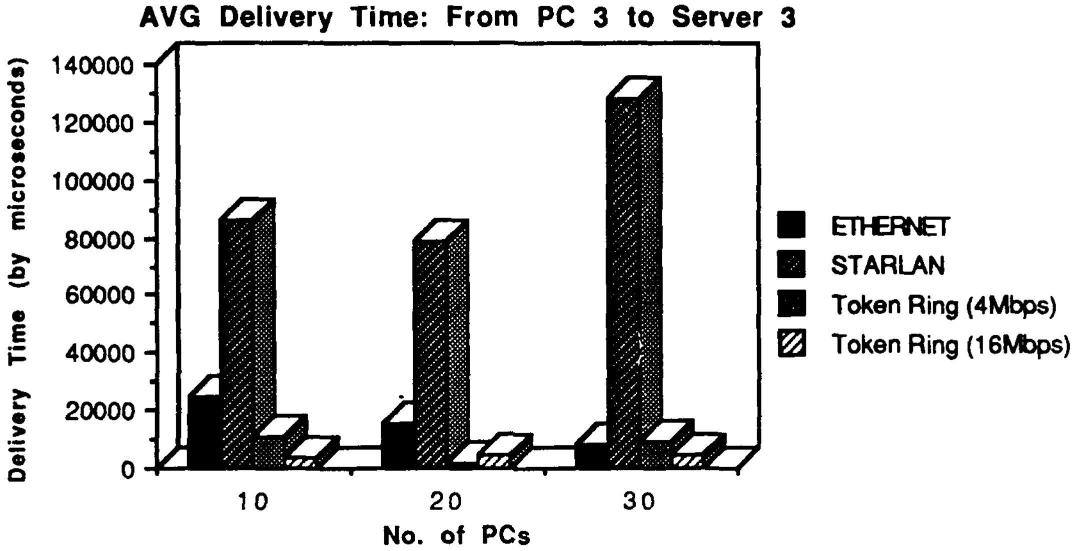



Figure 49. AVG Delivery Time for Transaction Class 3 with Two Servers: From PC to Server

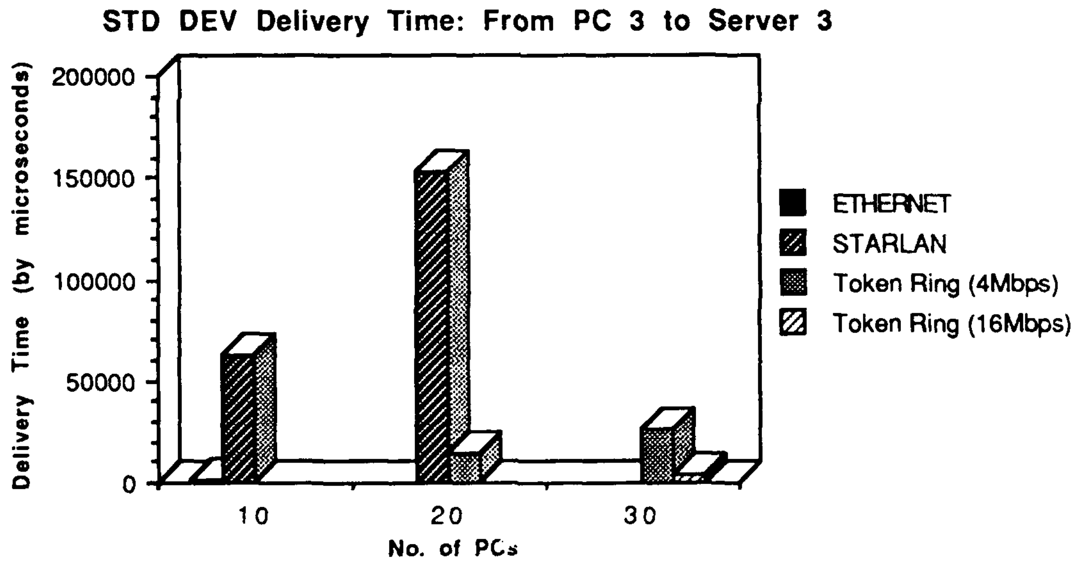



Figure 50. STD DEV Delivery Time for Transaction Class 3 with One Server: From PC to Server

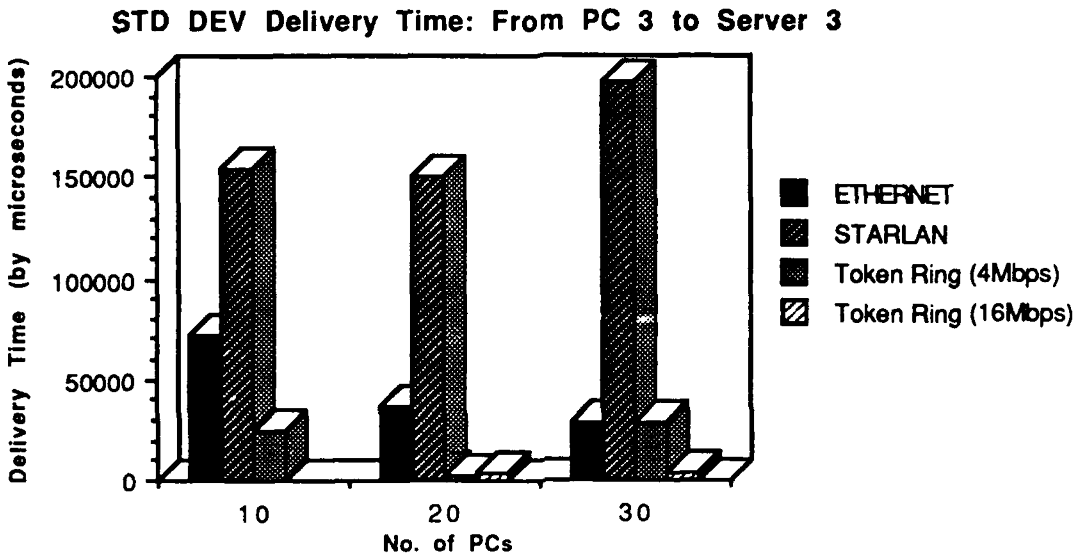



**Figure 51. STD DEV Delivery Time for Transaction Class 3 with Two Servers: From PC to Server**

In Tables 33-36 and Figures 52-55, the STD DEV delivery time decrease only for the Token Ring (16Mbps) with 30 PCs as another server is added.

**TABLE 33. AVG DELIVERY TIME FOR TRANSACTION CLASS 3 WITH ONE SERVER: FROM SERVER TO PC**

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 154400.000 | 521976.000 | 129645.700 | 38144.000 |
| 20 PCs | 154400.000 | 521976.000 | 129600.000 | 38144.000 |
| 30 PCs | 154766.400 | * | 129600.000 | 38165.000 |

* : No results for "Insufficient Memory"

**TABLE 34. AVG DELIVERY TIME FOR TRANSACTION CLASS 3 WITH TWO SERVERS: FROM SERVER TO PC**

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 166039.846 | 562033.846 | 139478.385 | 38144.000 |
| 20 PCs | 154400.000 | 521976.000 | 129600.000 | 38144.000 |
| 30 PCs | 154749.350 | 544581.944 | 129607.650 | 38154.000 |

TABLE 35. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 3 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 0.000 | 0.000 | 137.100 | 0.000 |
| 20 PCs | 0.000 | 0.000 | 0.000 | 0.000 |
| 30 PCs | 761.249 | * | 0.000 | 68.133 |

* : No results for "Insufficient Memory"

TABLE 36. STD DEV DELIVERY TIME FOR TRANSACTION CLASS 3 WITH TWO SERVERS: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 39741.251 | 138764.450 | 34219.728 | 0.000 |
| 20 PCs | 0.000 | 0.000 | 0.000 | 0.000 |
| 30 PCs | 910.392 | 84933.083 | 33.346 | 49.367 |

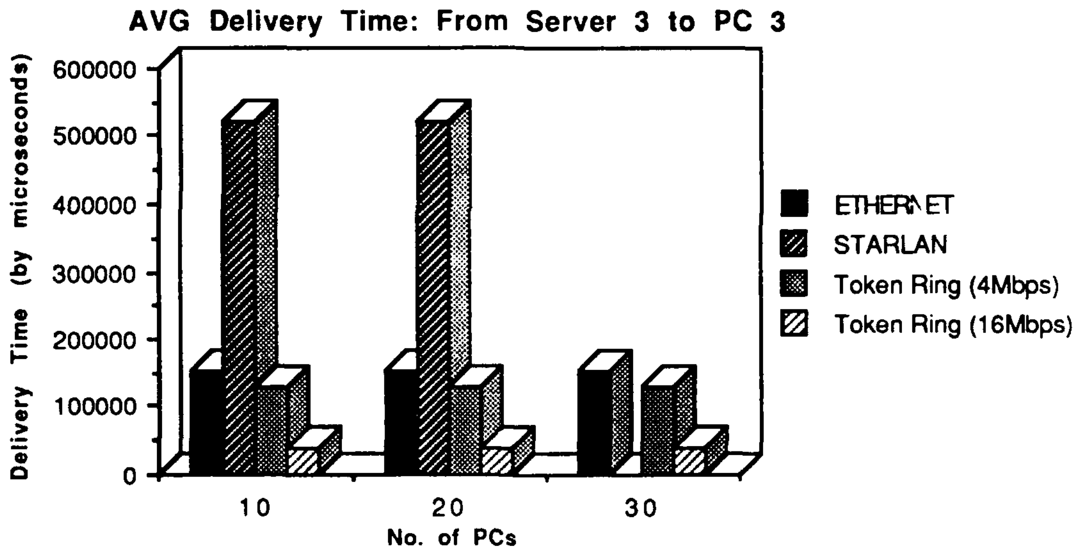



Figure 52. AVG Delivery Time for Transaction Class 3 with One Server: From Server to PC

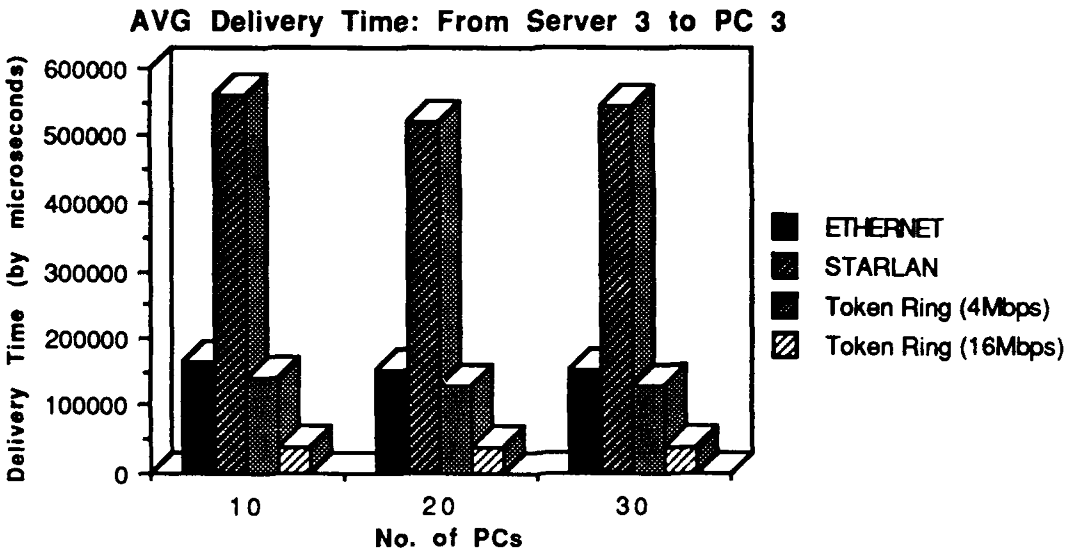



Figure 53. AVG Delivery Time for Transaction Class 3 with Two Servers: From Server to PC

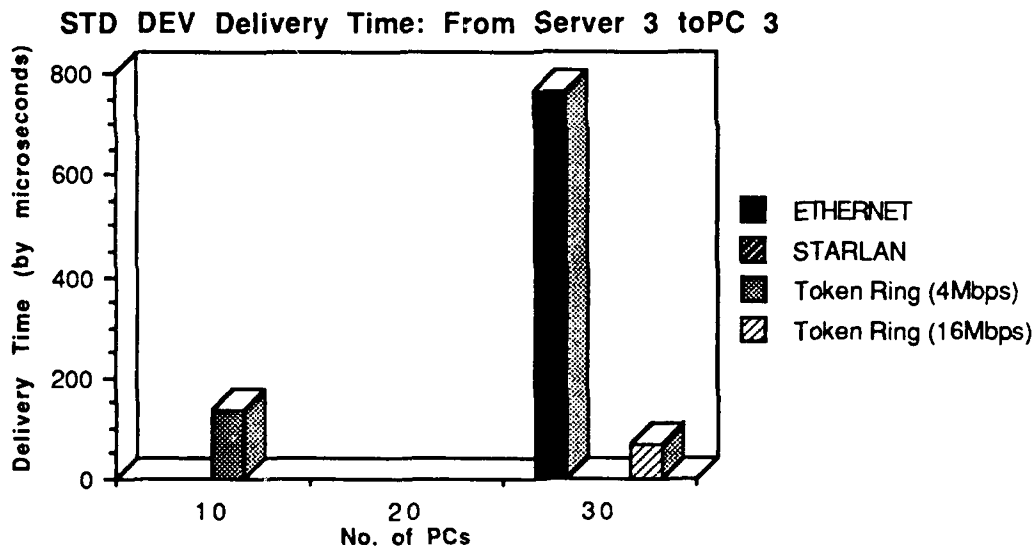



Figure 54. STD DEV Delivery Time for Transaction Class 3 with One Server: From Server to PC

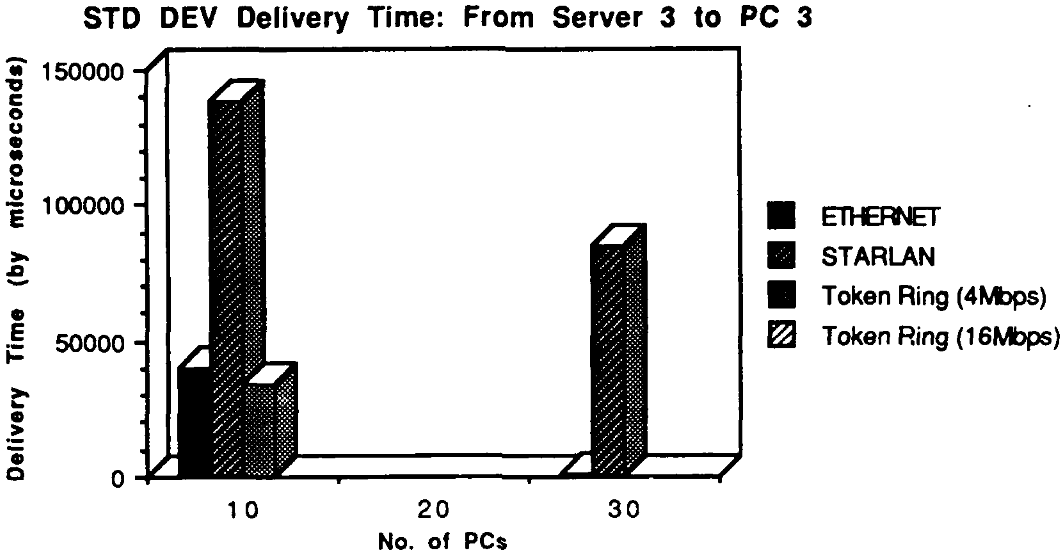



Figure 55. STD DEV Delivery Time for Transaction Class 3 with Two Servers: From Server to PC

# V. CONCLUSION

A queueing network model is an analytical tool used to capture the interactions between CPU, disk, LLC, and MAC based on assumptions on stochastic distributions for the arrival rate or workload in the LAN system. In a hierarchical queueing network, the use of FESC can simplify the complicated operations of LAN components by abstraction. However, queueing network models are impractical for their theoretical complexities and cannot be generally used. We discussed how a queueing network model is formulated for our problem without offering solution approaches. Then we relied on simulations for our experiments to show actual performance of various LAN configurations.

By using the SIMLAN II, we analyze the performance of CSMA/CD bus and Token Ring under various LAN configurations, i.e., under various numbers of servers and PCs in the LAN. From the results of simulation, we found the LAN utilization, request delay and delivery time will increase as another server is added. It is shown that response time increases as the number of servers increases, because more traffic would flow over the LAN. The Token Ring is the best choice for the large number of PCs in the LAN. For less than 30 PCs, Ethernet or STARLAN may be satisfactory.

The restriction of SIMLAN II is that it can only be applied to the IEEE 802.3, 802.4, and 802.5. The IEEE 802.6 is not included in the package, so programming is the only way to analyze the optical fiber LAN.

## REFERENCES


1. Lazowska, E. D., *Quantitative System Performance,* Prentice-Hall Inc., 1984.

2. Stallings, W., *Data and Computer Communications,* second edition, Macmillian Publishing Company, 1988.

3. Marney-Petix, V., *Networking and Data Communication,* Reston Publishing Company, Inc., 1986.

4. Madron, T. W., *Local Area Networks: The Second Generation,* John Wiley & Sons, Inc., 1988.

5. Stallings, W., *Handbook of Computer-Communications Standard: Local Network Standard,* v. 2, Howard W. Sams & Company, 1987.

6. Ross, S. M., *Introduction to Probability Models,* Fourth Edition, Academic Press, Inc., 1989.

# APPENDIX A. SUPPLEMENTARY TABLES AND FIGURES

## TABLE A-1. MAX DELIVERY TIME FOR TRANSACTION CLASS 1WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 146007.000 | 435447.000 | 108054.000 | 26360.000 |
| 20 PCs | 152157.000 | 490671.000 | 109752.000 | 6275.000 |
| 30 PCs | 155417.000 | * | 127428.000 | 40494.000 |

* : No results for "Insufficient Memory"

## TABLE A-2. MAX DELIVERY TIME FOR TRANSACTION CLASS 1WITH TWO SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 131090.000 | 510975.000 | 109065.000 | 15458.000 |
| 20 PCs | 127994.000 | 503742.000 | 121687.000 | 43629.000 |
| 30 PCs | 326078.000 | 1168799.000 | 127428.000 | 40494.000 |

## TABLE A-3. MIN DELIVERY TIME FOR TRANSACTION CLASS 1WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2401.000 | 243.000 | 803.000 | 3201.000 |
| 20 PCs | 2402.000 | 256.000 | 806.000 | 3201.000 |
| 30 PCs | 2400.000 | * | 802.000 | 3200.000 |

* : No results for "Insufficient Memory"

## TABLE A-4. MIN DELIVERY TIME FOR TRANSACTION CLASS 1WITH TWO SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2401.000 | 243.000 | 803.000 | 3201.000 |
| 20 PCs | 2402.000 | 266.000 | 806.000 | 3201.000 |
| 30 PCs | 2401.000 | 237.000 | 801.000 | 3200.000 |

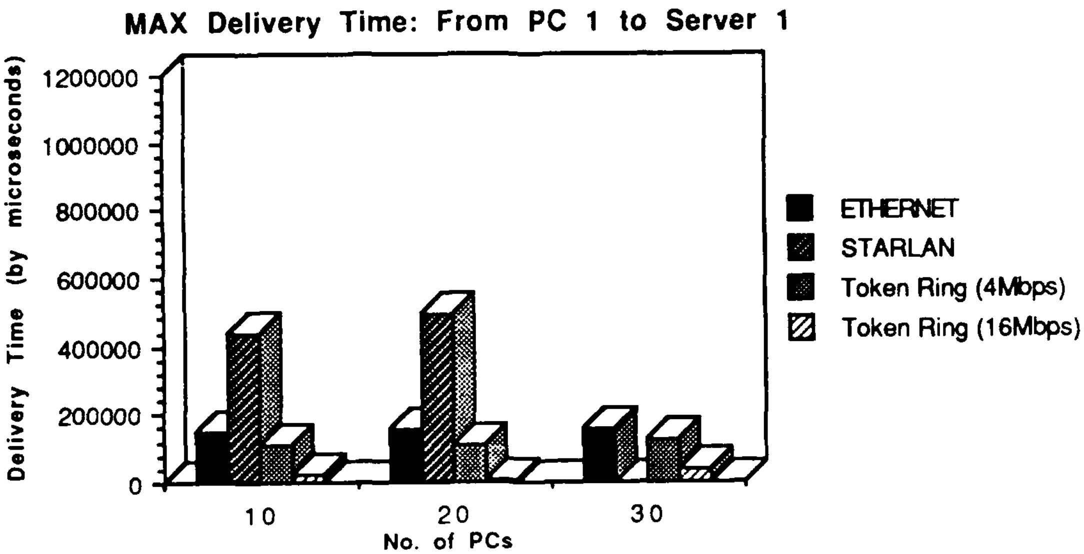



Figure A-1. MAX Delivery Time for Transaction Class 1 with One Server: From PC to Server

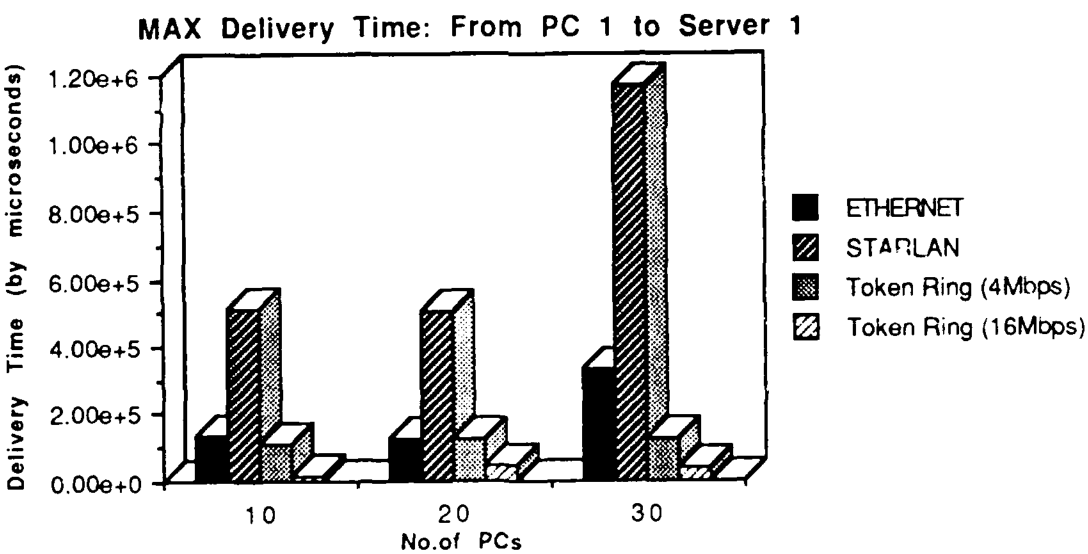



Figure A-2. MAX Delivery Time for Transaction Class 1 with Two Server: From PC to Server

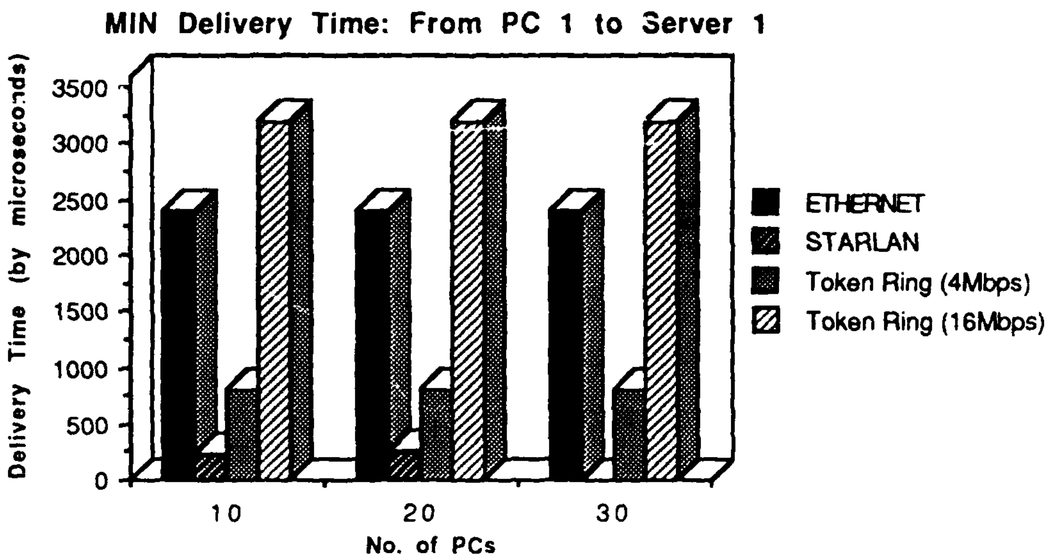



Figure A-3. MIN Delivery Time for Transaction Class 1 with One Server: From PC to Server

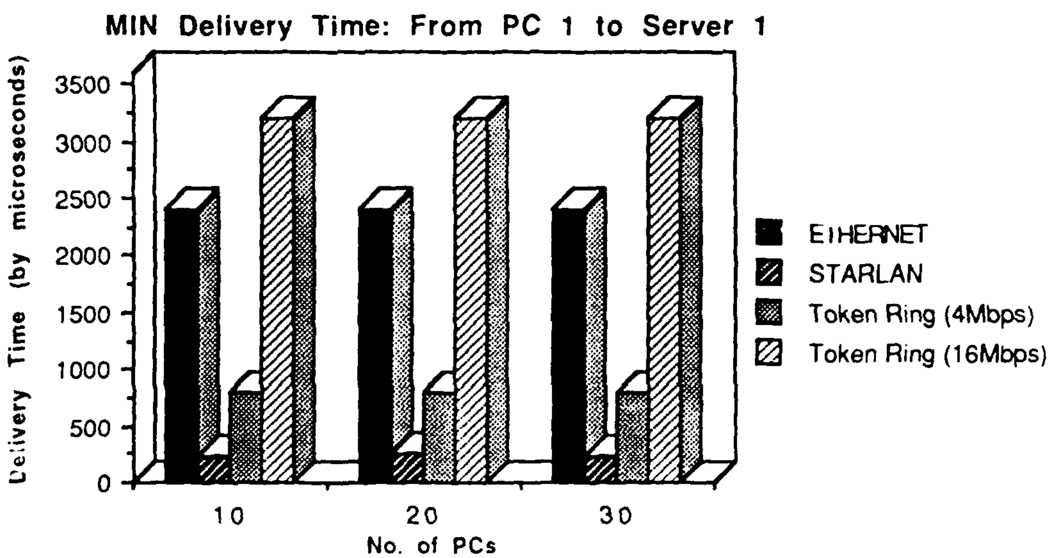



Figure A-4.. MIN Delivery Time for Transaction Class 1 with Two Server: From PC to Server

TABLE A-5. MAX DELIVERY TIME FOR TRANSACTION CLASS 1 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 8794.000 | 6212.000 | 100824.000 | 5614.000 |
| 20 PCs | 155241.000 | 510562.000 | 2194.000 | 7710.000 |
| 30 PCs | 152893.000 | * | 118478.000 | 38507.000 |

* : No results for "Insufficient Memory"

TABLE A-6. MAX DELIVERY TIME FOR TRANSACTION CLASS 1 WITH TWO SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 158139.000 | 18674.000 | 1824.000 | 39329.000 |
| 20 PCs | 147353.000 | 35265.000 | 114821.000 | 32764.000 |
| 30 PCs | 142515.000 | 1094889.000 | 134357.000 | 39547.000 |

TABLE A-7. MIN DELIVERY TIME FOR TRANSACTION CLASS 1 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2810.000 | 4328.000 | 1824.000 | 3454.000 |
| 20 PCs | 2810.000 | 4328.000 | 1824.000 | 3454.000 |
| 30 PCs | 2810.000 | * | 1824.000 | 3454.000 |

* : No results for "Insufficient Memory"

TABLE A-8. MIN DELIVERY TIME FOR TRANSACTION CLASS 1 WITH TWO SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2810.000 | 4328.000 | 1824.000 | 3454.000 |
| 20 PCs | 2810.000 | 4328.000 | 1824.000 | 3454.000 |
| 30 PCs | 2810.000 | 4328.000 | 1824.000 | 3454.000 |

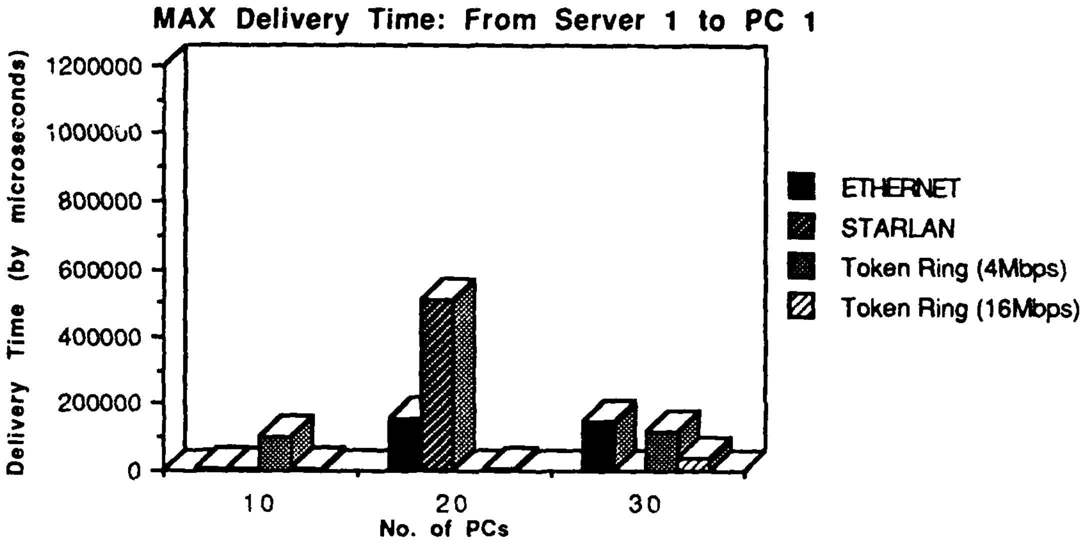



Figure A-5. MAX Delivery Time for Transaction Class 1 with One Server: From Server to PC

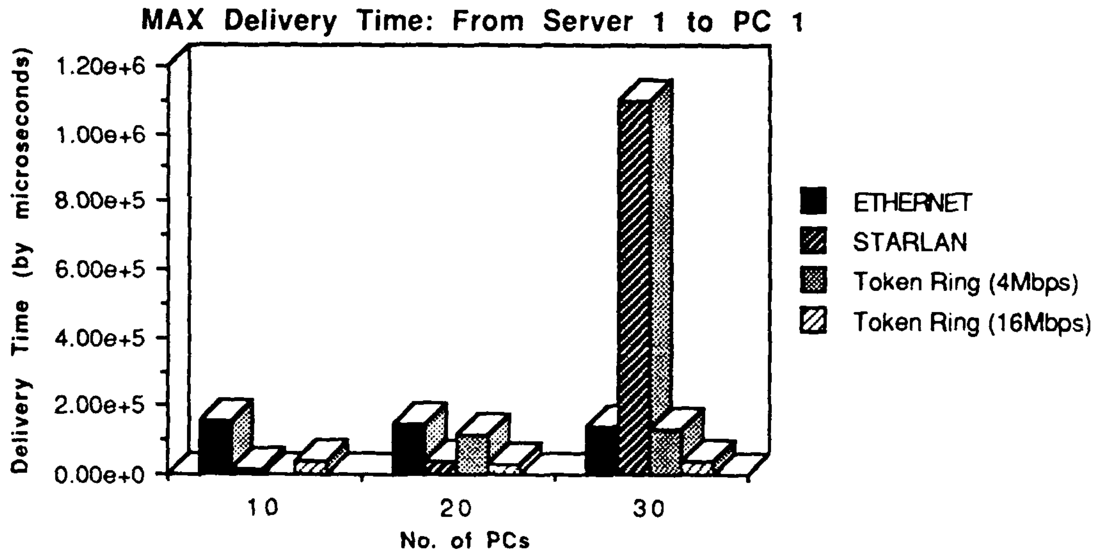



Figure A-6. MAX Delivery Time for Transaction Class 1 with Two Server: From Server to PC

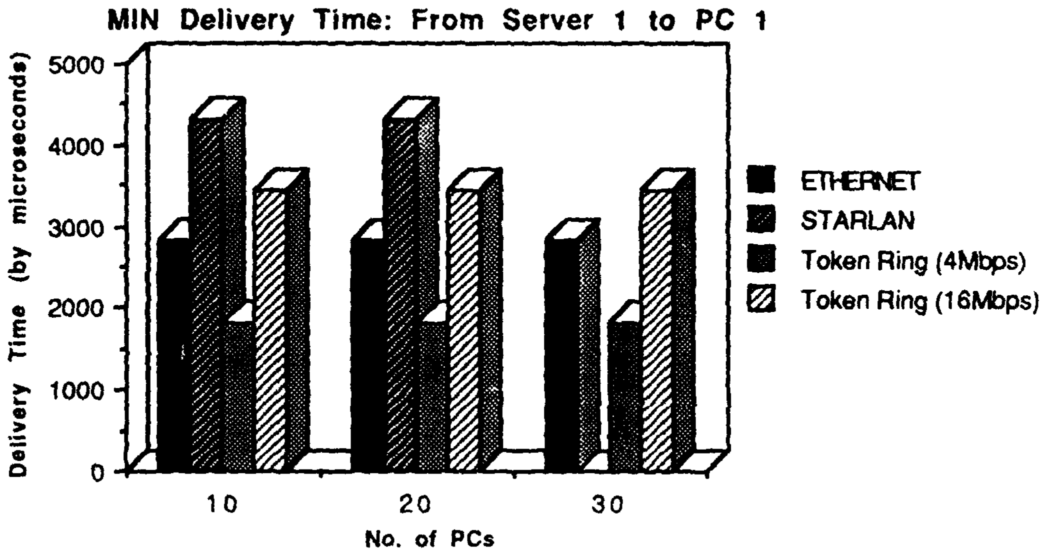



Figure A-7. MIN Delivery Time for Transaction Class 1 with One Server: From Server to PC

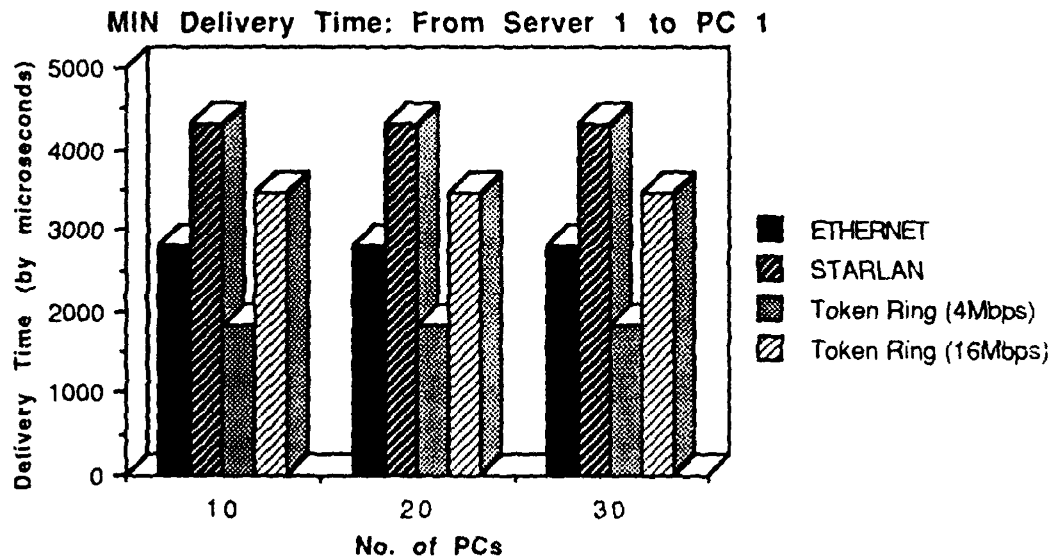



Figure A-8. MIN Delivery Time for Transaction Class 1 with Two Server: From Server to PC

## TABLE A-9. MAX DELIVERY TIME FOR TRANSACTION CLASS 2WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 143893.000 | 473898.000 | 26671.000 | 6092.000 |
| 20 PCs | 139621.000 | 328713.000 | 80255.000 | 6452.000 |
| 30 PCs | 155033.000 | * | 97996.000 | 42407.000 |

* : No results for "Insufficient Memory"

## TABLE A-10. MAX DELIVERY TIME FOR TRANSACTION CLASS 2WITH TWO SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 14264.000 | 348339.000 | 90805.000 | 6092.000 |
| 20 PCs | 136743.000 | 501624.000 | 108346.000 | 6452.000 |
| 30 PCs | 147491.000 | 809344.000 | 97996.000 | 42407.000 |

## TABLE A-11. MIN DELIVERY TIME FOR TRANSACTION CLASS 2WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2412.000 | 347.000 | 829.000 | 3207.000 |
| 20 PCs | 2410.000 | 327.000 | 824.000 | 3206.000 |
| 30 PCs | 2406.000 | * | 814.000 | 3211.000 |

* : No results for "Insufficient Memory"

## TABLE A-12. MIN DELIVERY TIME FOR TRANSACTION CLASS 2WITH TWO SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2412.000 | 347.000 | 829.000 | 3207.000 |
| 20 PCs | 2410.000 | 327.000 | 824.000 | 3206.000 |
| 30 PCs | 2406.000 | 288.000 | 814.000 | 3211.000 |

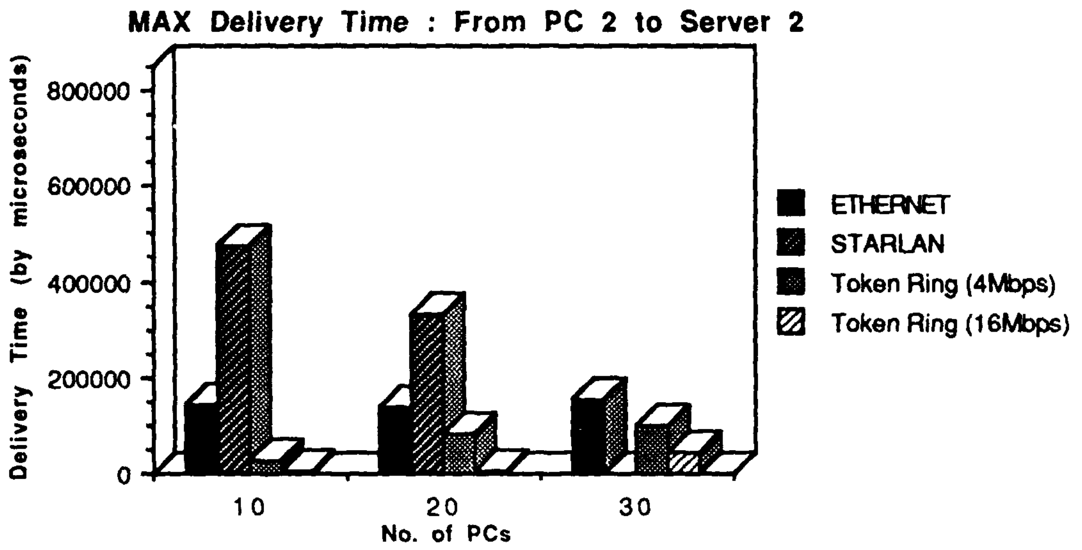



Figure A-9. MAX Delivery Time for Transaction Class 2 with One Server: From PC to Server

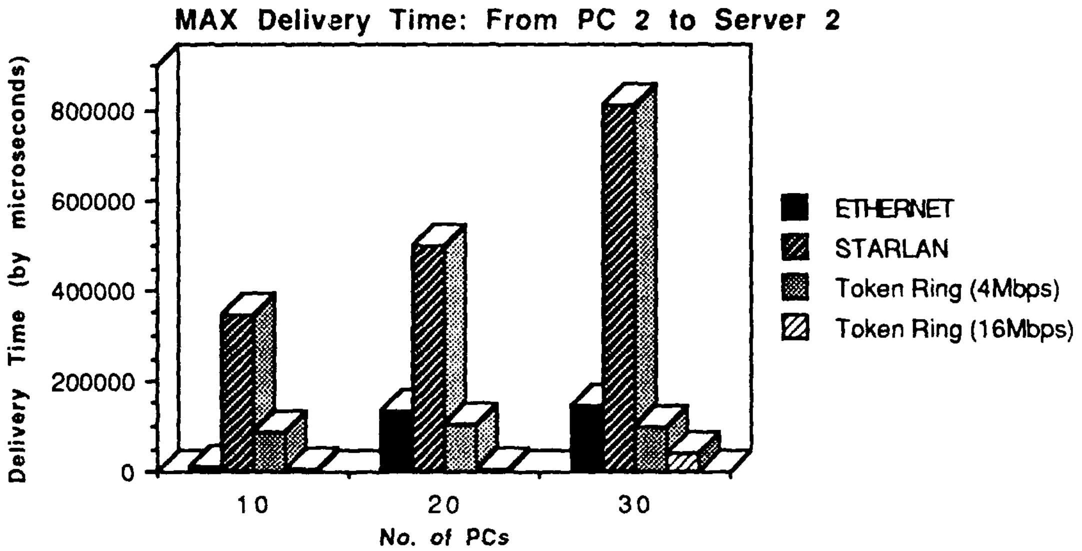



Figure A-10. MAX Delivery Time for Transaction Class 2 with Two Server: From PC to Server

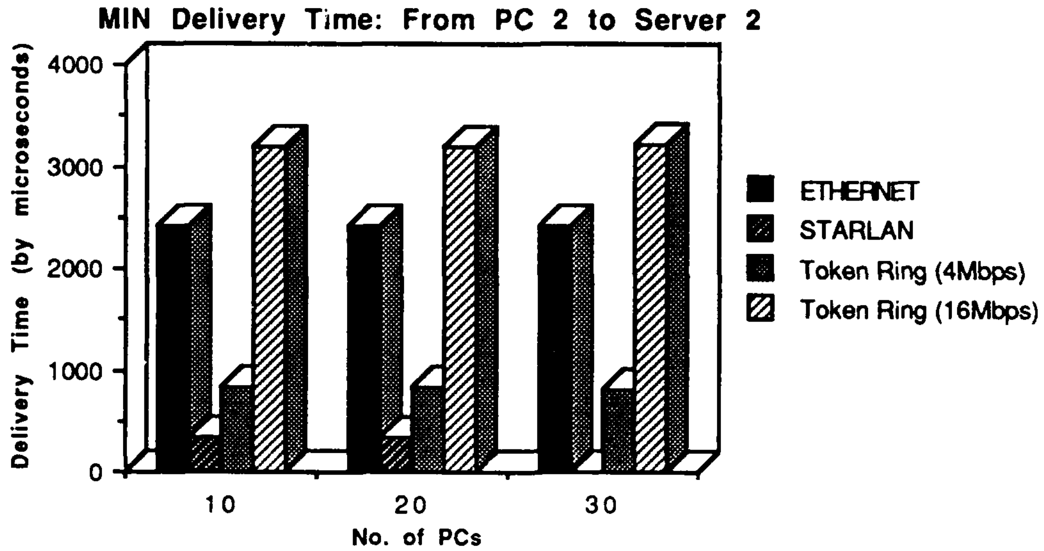



Figure A-11. MIN Delivery Time for Transaction Class 2 with One Server: From PC to Server

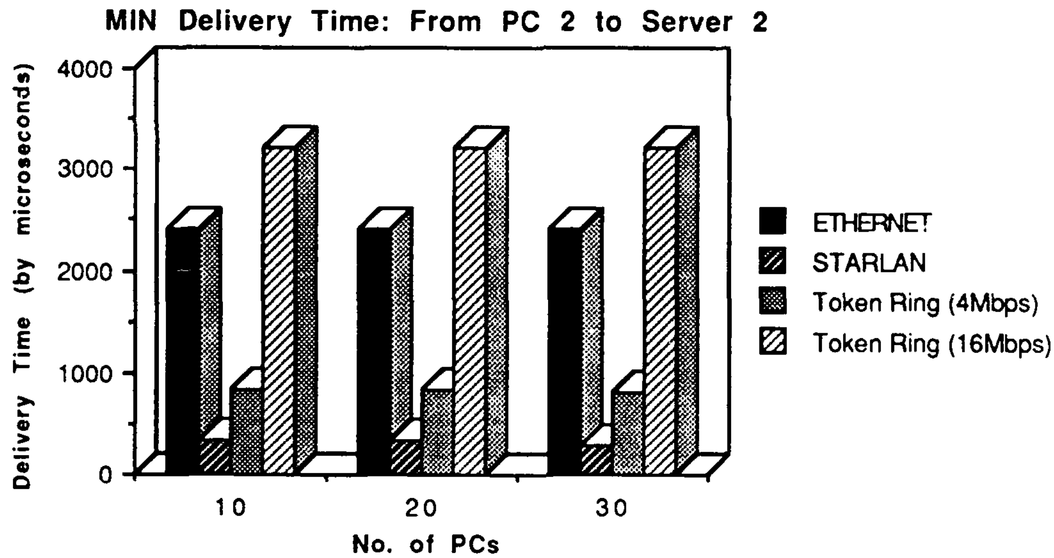



Figure A-12. MIN Delivery Time for Transaction Class 2 with Two Server: From PC to Server

TABLE A-13. MAX DELIVERY TIME FOR TRANSACTION CLASS 2 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 6315.000 | 5450.000 | 1056.000 | 3263.000 |
| 20 PCs | 6609.000 | 15485.000 | 9091.000 | 6344.000 |
| 30 PCs | 144219.000 | * | 11864.000 | 3263.000 |

* : No results for "Insufficient Memory"

TABLE A-14. MAX DELIVERY TIME FOR TRANSACTION CLASS 2 WITH TWO SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2502.000 | 1256.000 | 1056.000 | 3263.000 |
| 20 PCs | 8010.000 | 11958.000 | 9091.000 | 41302.000 |
| 30 PCs | 155494.000 | 798741.000 | 11864.000 | 31291.000 |

TABLE A-15. MIN DELIVERY TIME FOR TRANSACTION CLASS 2 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2502.000 | 1256.000 | 1056.000 | 3263.000 |
| 20 PCs | 2502.000 | 1256.000 | 1056.000 | 3263.000 |
| 30 PCs | 2502.000 | * | 1056.000 | 3263.000 |

* : No results for "Insufficient Memory"

TABLE A-16. MIN DELIVERY TIME FOR TRANSACTION CLASS 2 WITH TWO SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2502.000 | 1256.000 | 1056.000 | 3263.000 |
| 20 PCs | 2502.000 | 1256.000 | 1056.000 | 3263.000 |
| 30 PCs | 2502.000 | 1256.000 | 1056.000 | 3263.000 |

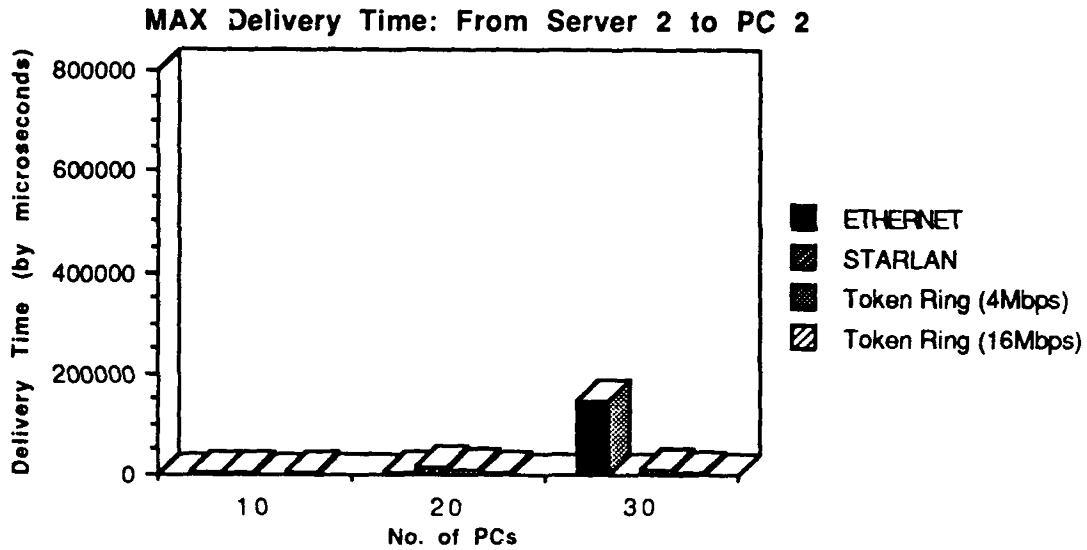



Figure A-13. MAX Delivery Time for Transaction Class 2 with One Server: From Server to PC

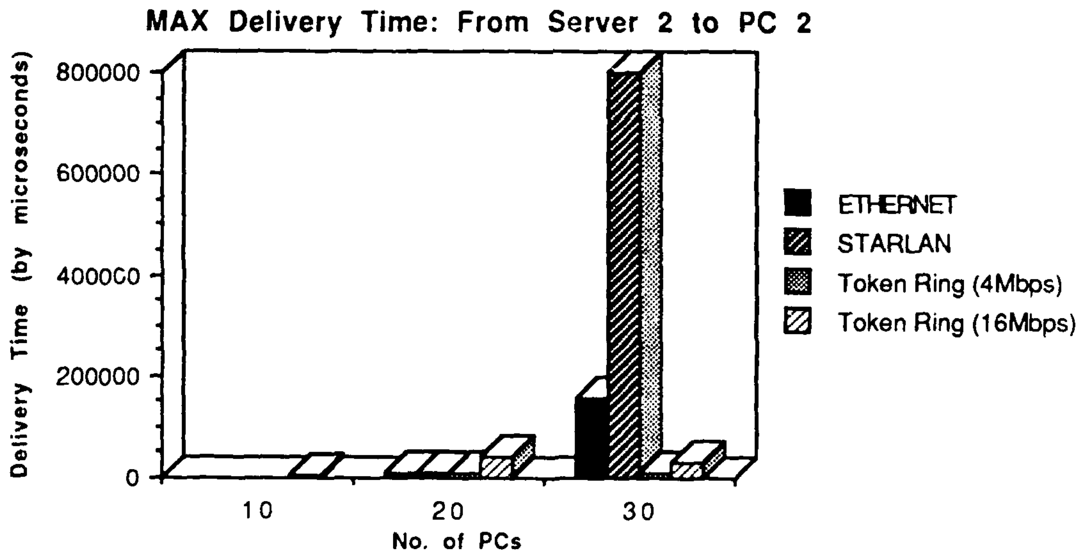



Figure A-14. MAX Delivery Time for Transaction Class 2 with Two Server: From Server to PC

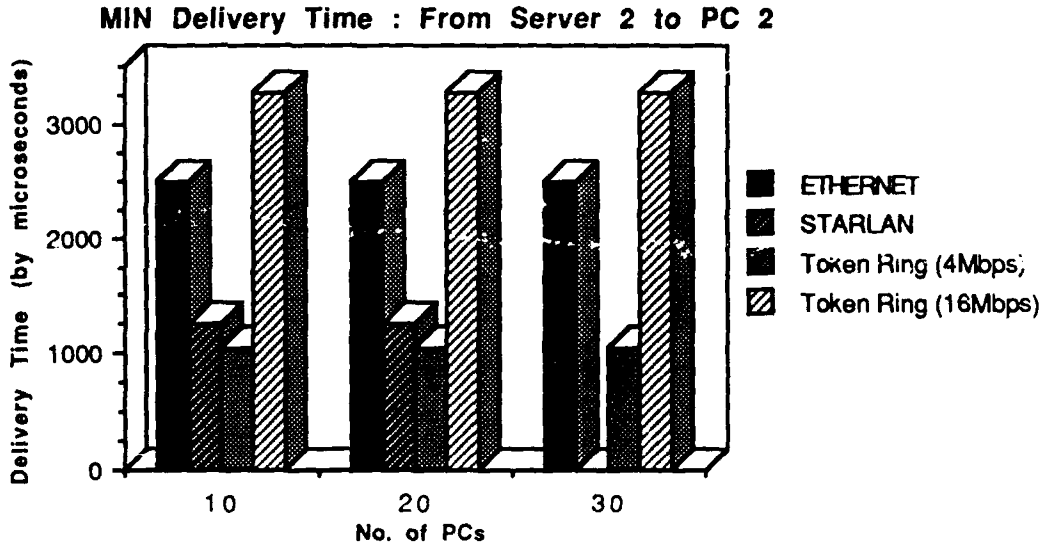



Figure A-15. MIN Delivery Time for Transaction Class 2 with One Server: From Server to PC

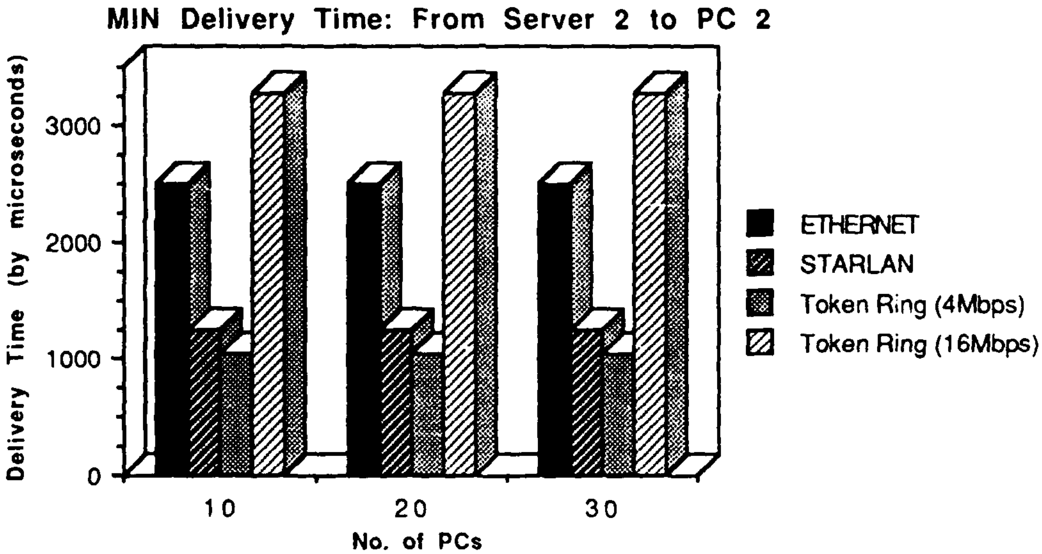



Figure A-16. MIN Delivery Time for Transaction Class 2 with Two Server: From Server to PC

## TABLE A-17. MAX DELIVERY TIME FOR TRANSACTION CLASS 3WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 6326.000 | 185017.000 | 1470.000 | 5778.000 |
| 20 PCs | 2731.000 | 525971.000 | 92288.000 | 5033.000 |
| 30 PCs | 4718.000 | * | 134042.000 | 27587.000 |

* : No results for "Insufficient Memory"

## TABLE A-18. MAX DELIVERY TIME FOR TRANSACTION CLASS 3 WITH TWO SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 304141.000 | 440109.000 | 98336.000 | 5778.000 |
| 20 PCs | 151551.000 | 509379.000 | 13834.000 | 41133.000 |
| 30 PCs | 158908.000 | 667231.000 | 134042.000 | 27587.000 |

## TABLE A-19. MIN DELIVERY TIME FOR TRANSACTION CLASS 3WITH ONE SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2402.000 | 242.000 | 806.000 | 3201.000 |
| 20 PCs | 2404.000 | 276.000 | 811.000 | 3203.000 |
| 30 PCs | 2403.000 | * | 807.000 | 3202.000 |

* : No results for "Insufficient Memory"

## TABLE A-20. MIN DELIVERY TIME FOR TRANSACTION CLASS 3 WITH TWO SERVER: FROM PC TO SERVER

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 2402.000 | 255.000 | 806.000 | 3201.000 |
| 20 PCs | 2404.000 | 289.000 | 811.000 | 3203.000 |
| 30 PCs | 2401.000 | 261.000 | 807.000 | 3202.000 |

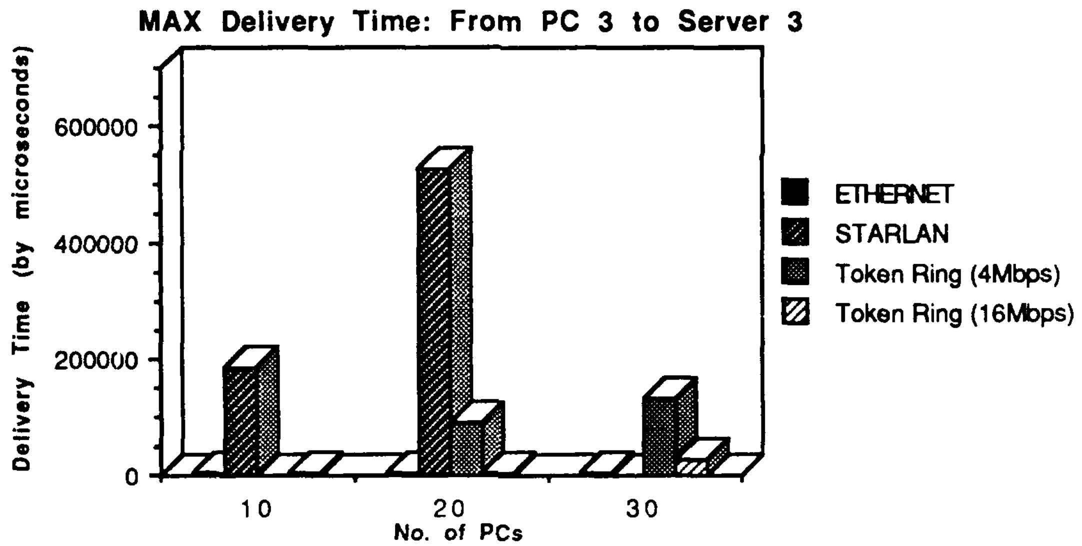



Figure A-17. MAX Delivery Time for Transaction Class 3 with One Server: From PC to Server

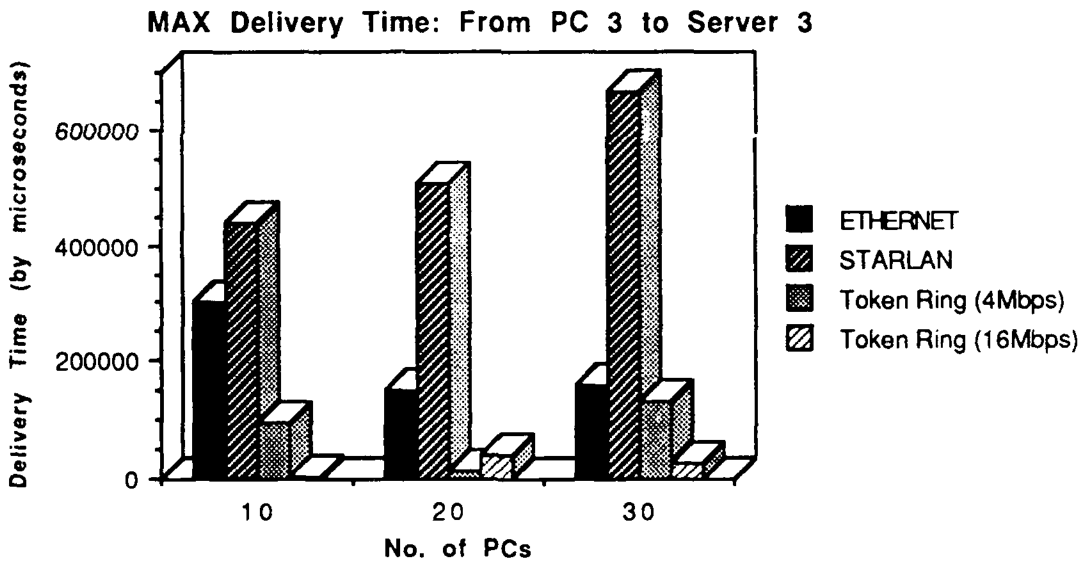



Figure A-18. MAX Delivery Time for Transaction Class 3 with Two Server: From PC to Server

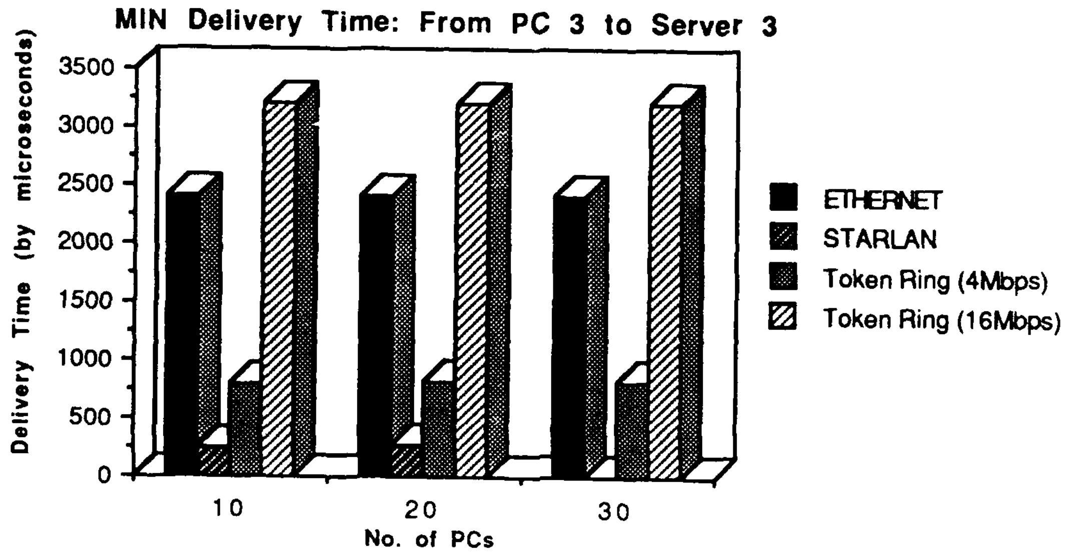



Figure A-19. MIN Delivery Time for Transaction Class 3 with One Server: From PC to Server

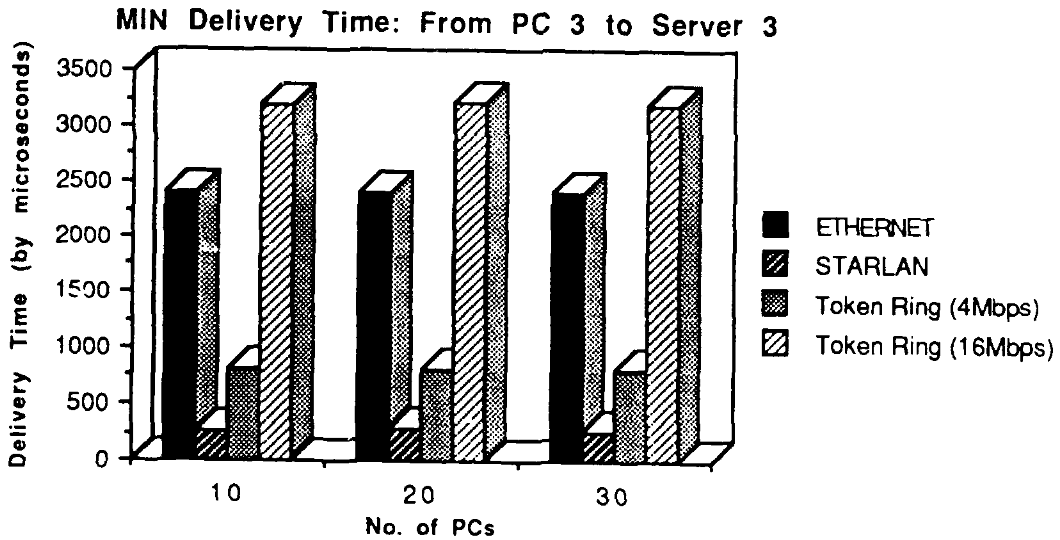



Figure A-20. MIN Delivery Time for Transaction Class 3 with Two Server: From PC to Server

TABLE A-21. MAX DELIVERY TIME FOR TRANSACTION CLASS 3 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 154400.000 | 521976.000 | 130057.000 | 38144.000 |
| 20 PCs | 154400.000 | 521976.000 | 129600.000 | 38144.000 |
| 30 PCs | 156693.000 | * | 129600.000 | 38381.545 |

* : No results for "Insufficient Memory"

TABLE A-22. MAX DELIVERY TIME FOR TRANSACTION CLASS 3 WITH TWO SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 303695.000 | 1042728.000 | 258019.000 | 38144.000 |
| 20 PCs | 154400.000 | 521976.000 | 129600.000 | 38144.000 |
| 30 PCs | 158041.000 | 893862.000 | 129753.000 | 38381.000 |

TABLE A-23. MIN DELIVERY TIME FOR TRANSACTION CLASS 3 WITH ONE SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 154400.000 | 521976.000 | 129600.000 | 38144.000 |
| 20 PCs | 154400.000 | 521976.000 | 129600.000 | 38144.000 |
| 30 PCs | 154400.000 | * | 129600.000 | 38144.000 |

* : No results for "Insufficient Memory"

TABLE A-24. MIN DELIVERY TIME FOR TRANSACTION CLASS 3 WITH TWO SERVER: FROM SERVER TO PC

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 154400.000 | 521976.000 | 129600.000 | 38144.000 |
| 20 PCs | 154400.000 | 521976.000 | 129600.000 | 38144.000 |
| 30 PCs | 154400.000 | 521976.000 | 129600.000 | 38144.000 |

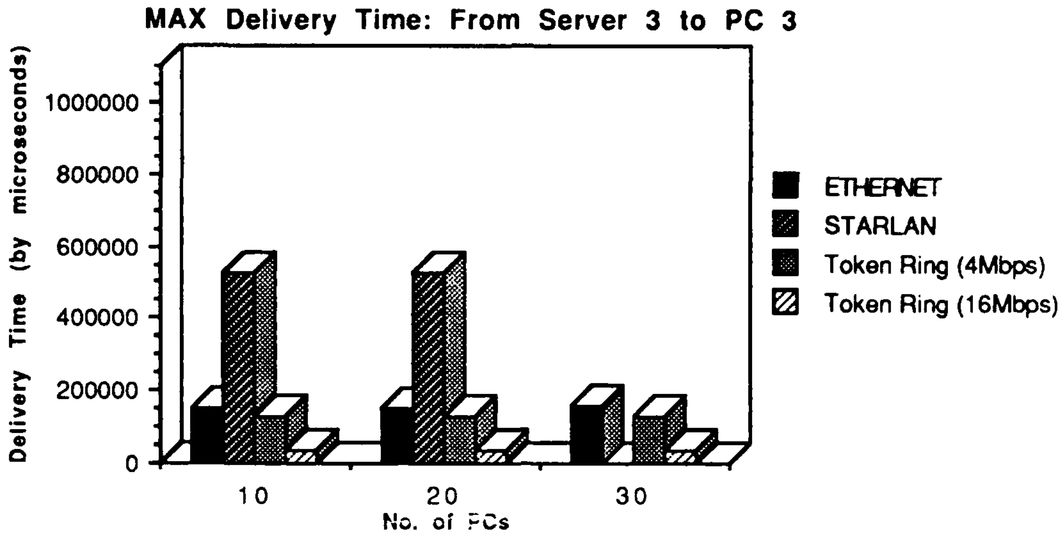



Figure A-21. MAX Delivery Time for Transaction Class 3 with One Server: From Server to PC

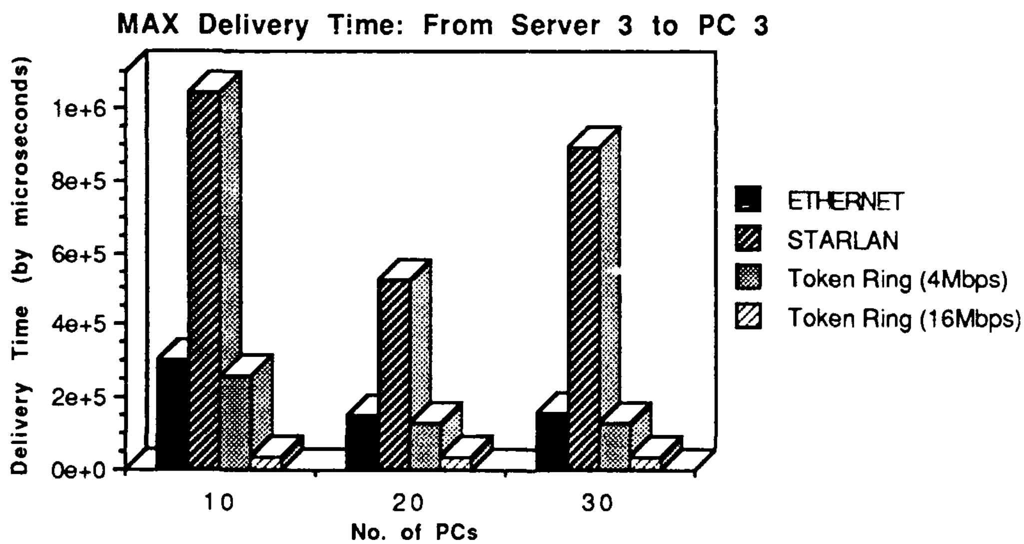



Figure A-22. MAX Delivery Time for Transaction Class 3 with Two Server: From Server to PC

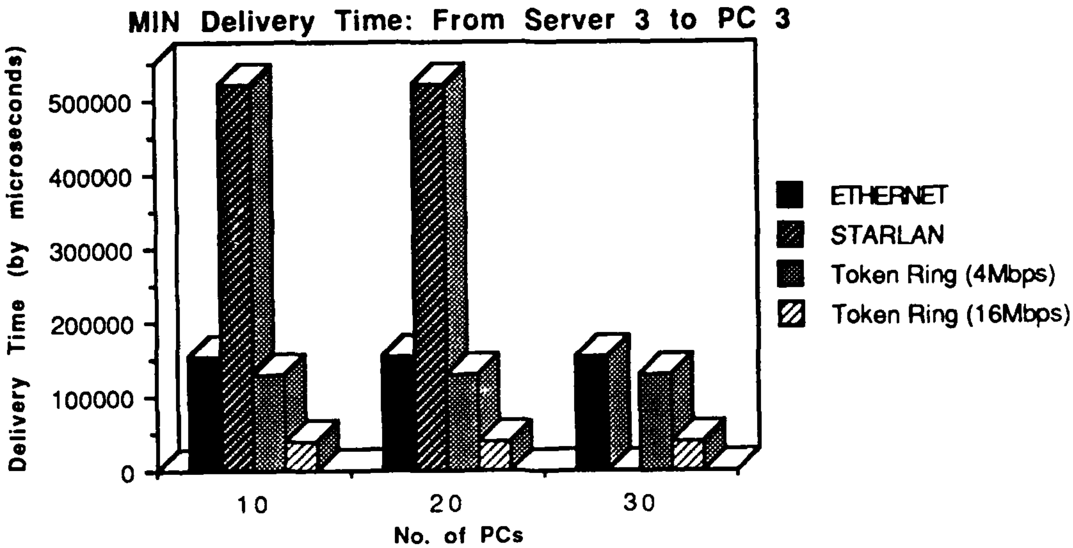



Figure A-23. MIN Delivery Time for Transaction Class 3 with One Server: From Server to PC

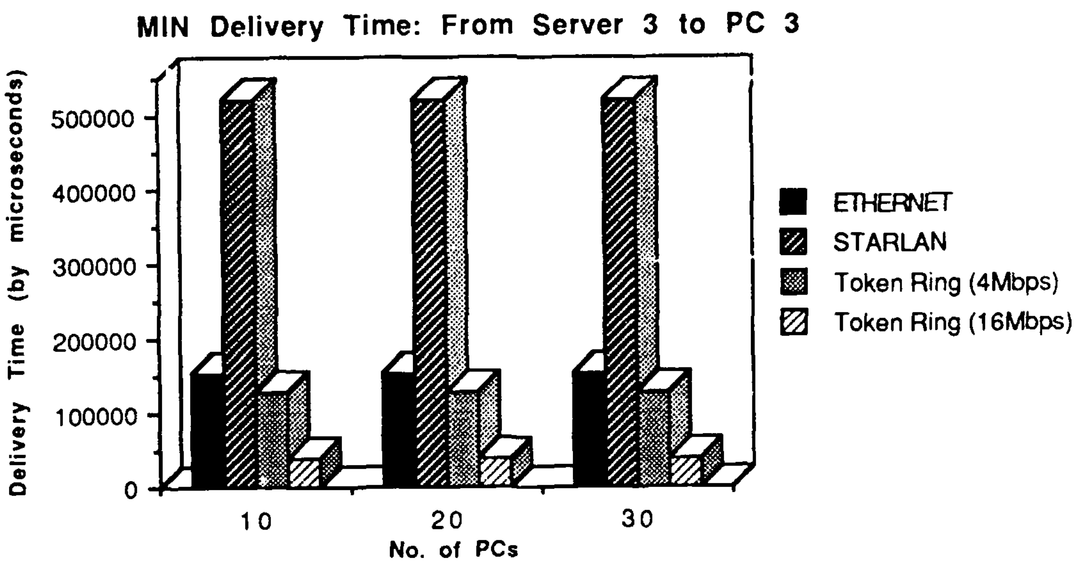



Figure A-24. MIN Delivery Time for Transaction Class 3 with Two Server: From Server to PC

TABLE A-25. INCOMPLETED TRANSFERS FOR CLASS 1 WITH ONE SERVER IN THE SIMULATION PERIOD

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 0.000% | 0.000% | 0.000% | 0.000% |
| 20 PCs | 2.174% | 0.000% | 1.087% | 1.087% |
| 30 PCs | 0.000% | * | 1.143% | 0.000% |

* : No results for "Insufficient Memory"

TABLE A-26. INCOMPLETED TRANSFERS FOR CLASS 1 WITH TWO SERVERS IN THE SIMULATION PERIOD

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 0.000% | 0.000% | 0.000% | 0.000% |
| 20 PCs | 1.087% | 0.000% | 1.087% | 1.087% |
| 30 PCs | 0.000% | 0.000% | 0.000% | 0.000% |

TABLE A-27. INCOMPLETED TRANSFERS FOR CLASS 3 WITH ONE SERVER IN THE SIMULATION PERIOD

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 41.176% | 47.058% | 41.176% | 35.294% |
| 20 PCs | 75.610% | 78.049% | 75.610% | 73.171% |
| 30 PCs | 80.456% | * | 82.456% | 80.702% |

* : No results for "Insufficient Memory"

TABLE A-28. INCOMPLETED TRANSFERS FOR CLASS 3 WITH TWO SERVERS IN THE SIMULATION PERIOD

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 23.529% | 23.529% | 23.529% | 23.529% |
| 20 PCs | 53.659% | 58.531% | 53.659% | 51.220% |
| 30 PCs | 64.912% | 68.421% | 64.912% | 61.404% |

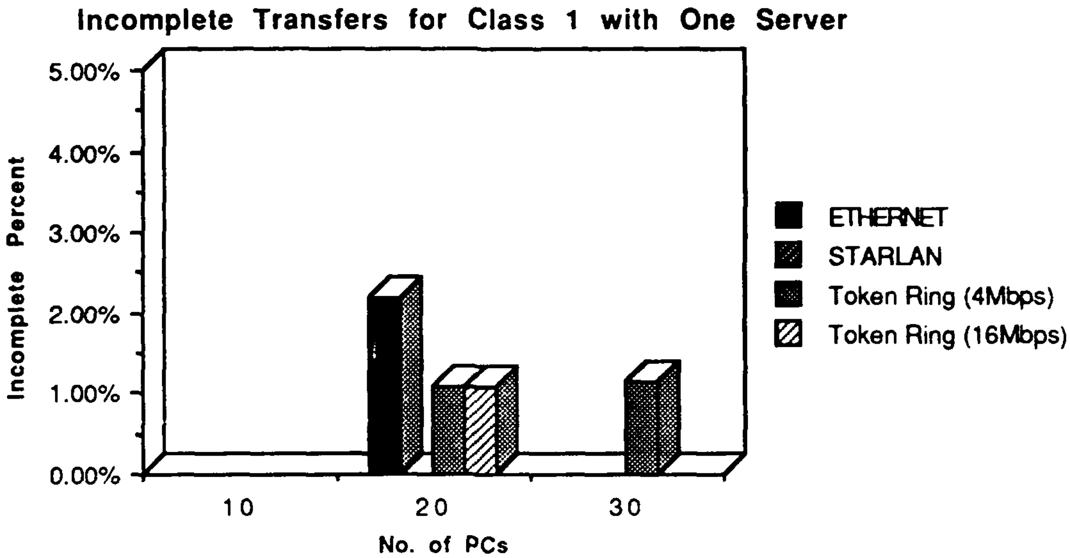



Figure A-25. Incompleted Transfers for Class 1 with One Server

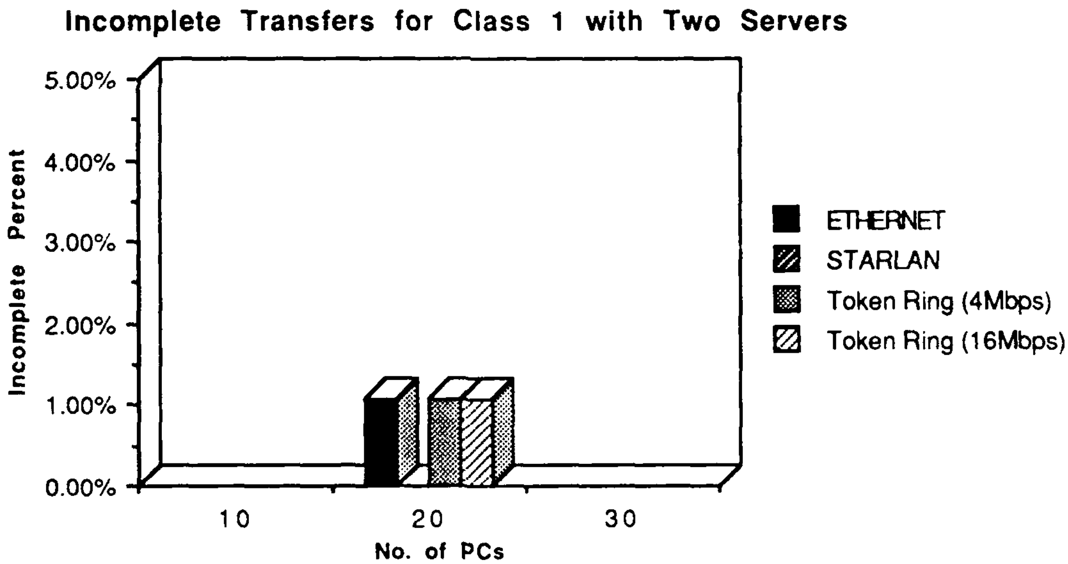



Figure A-26. Incompleted Transfers for Class 1 with Two Servers

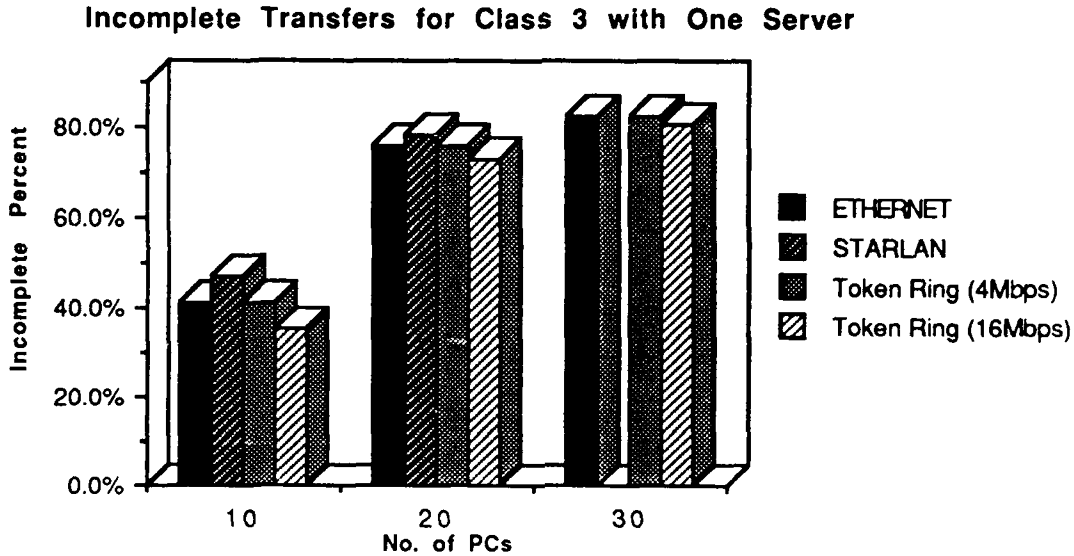



Figure A-27. Incompleted Transfers for Class 3 with One Server

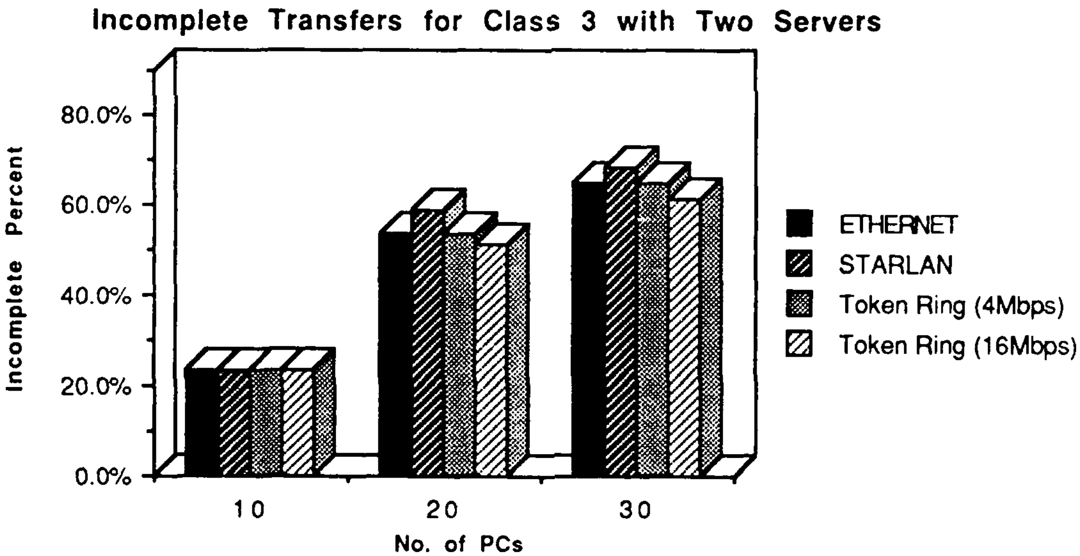



Figure A-28. Incompleted Transfers for Class 3 with Two Servers

TABLE A-29. INCOMPLETED TRANSFERS FOR CLASS 2 WITH ONE SERVER IN THE SIMULATION PERIOD

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 0.000% | 0.000% | 0.000% | 0.000% |
| 20 PCs | 0.000% | 0.000% | 0.000% | 0.000% |
| 30 PCs | 0.000% | * | 0.000% | 0.000% |

* : No results for "Insufficient Memory"

TABLE A-30. INCOMPLETED TRANSFERS FOR CLASS 2 WITH TWO SERVERS IN THE SIMULATION PERIOD

| No. of PCs | ETHERNET | STARLAN | TokenRing(4Mbps) | Token Ring (16Mbps) |
|---|---|---|---|---|
| 10 PCs | 0.000% | 0.000% | 0.000% | 0.000% |
| 20 PCs | 0.000% | 0.000% | 0.000% | 0.000% |
| 30 PCs | 0.000% | 0.000% | 0.000% | 0.000% |

# APPENDIX B. PRINTOUTS FROM SIMULATIONS

SIMLAN II RELEASE 1.01 02/19/1990 03:08:50 PAGE 1

ETHERNET FOR THREE SERVERS AND 30 PCs

COLLISION LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | COLLISION |
|---|---|
| COLLISION EPISODES | 3 |
| COLLIDED TRANSFERS | 8 |
| DEFERRALS | 17 |
| AVG DEFERRAL DELAY | 50151.580 |
| MAX DEFERRAL DELAY | 143195.535 |
| STD DEV DEFERRAL DELAY | 59763.925 |
| AVG DEFERRAL QUEUE | .028 |
| MAX QUEUE SIZE | 2.000 |
| STD DEV QUEUE SIZE | .207 |
| MULTIPLE COLLISIONS | 1 |
| AVG MULT COLLISIONS | 4.000 |
| MAX MULT COLLISIONS | 4 |
| SUCCESSFUL TRANSFERS | 205 |
| AVG USAGE TIME | 10357.364 |
| MAX USAGE TIME | 154400.000 |
| STD DEV USAGE TIME | 32655.045 |
| PER CENT OF TIME BUSY | 7.078 |

CACI SIMLAN II RELEASE 1.01 02/19/1990 03:08:50 PAGE 5

ETHERNET FOR THREE SERVERS AND 30 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 62 | 62 | 27 | 27 | 17 | 10 |
| AVG DELIVERY TIME | 11867.968 | 2938.081 | 14649.963 | 2643.222 | 2815.647 | 154400.000 |
| MAX DELIVERY TIME | 146007.000 | 8794.000 | 143893.000 | 6315.000 | 6326.000 | 154400.000 |
| MIN DELIVERY TIME | 2401.000 | 2810.000 | 2412.000 | 2502.000 | 2402.000 | 154400.000 |
| STD DEV DELIVERY TIME | 32615.725 | 789.253 | 34897.673 | 720.095 | 916.435 | 0. |

ETHERNET FOR THREE SERVERS AND 60 PCs

COLLISION LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | COLLISION |
|---|---|
| COLLISION EPISODES | 5 |
| COLLIDED TRANSFERS | 11 |
| DEFERRALS | 21 |
| AVG DEFERRAL DELAY | 56127.702 |
| MAX DEFERRAL DELAY | 149720.121 |
| STD DEV DEFERRAL DELAY | 63061.845 |
| AVG DEFERRAL QUEUE | .039 |
| MAX QUEUE SIZE | 2.000 |
| STD DEV QUEUE SIZE | .223 |
| MULTIPLE COLLISIONS | 1 |
| AVG MULT COLLISIONS | 3.000 |
| MAX MULT COLLISIONS | 3 |
| SUCCESSFUL TRANSFERS | 333 |
| AVG USAGE TIME | 7476.666 |
| MAX USAGE TIME | 154400.000 |
| STD DEV USAGE TIME | 25805.731 |
| PER CENT OF TIME BUSY | 8.299 |

ETHERNET FOR THREE SERVERS AND 60 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 92 | 90 | 50 | 50 | 41 | 10 |
| AVG DELIVERY TIME | 9062.533 | 6160.555 | 10058.760 | 2637.700 | 2502.780 | 154400.000 |
| MAX DELIVERY TIME | 152157.000 | 155241.000 | 139621.000 | 6609.000 | 2731.000 | 154400.000 |
| MIN DELIVERY TIME | 2402.000 | 2810.000 | 2410.000 | 2502.000 | 2404.000 | 154400.000 |
| STD DEV DELIVERY TIME | 27131.115 | 21884.704 | 25831.664 | 625.415 | 85.882 | 0. |

ETHERNET FOR THREE SERVERS AND 90 PCs

COLLISION LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | COLLISION |
|---|---|
| COLLISION EPISODES | 16 |
| COLLIDED TRANSFERS | 44 |
| DEFERRALS | 58 |
| AVG DEFERRAL DELAY | 25478.260 |
| MAX DEFERRAL DELAY | 152769.045 |
| STD DEV DEFERRAL DELAY | 47855.382 |
| AVG DEFERRAL QUEUE | .049 |
| MAX QUEUE SIZE | 4.000 |
| STD DEV QUEUE SIZE | .281 |
| MULTIPLE COLLISIONS | 7 |
| AVG MULT COLLISIONS | 3.714 |
| MAX MULT COLLISIONS | 5 |
| SUCCESSFUL TRANSFERS | 563 |
| AVG USAGE TIME | 5520.666 |
| MAX USAGE TIME | 154400.000 |
| STD DEV USAGE TIME | 20053.214 |
| PER CENT OF TIME BUSY | 10.366 |

ETHERNET FOR THREE SERVERS AND 90 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 173 | 173 | 75 | 75 | 57 | 10 |
| AVG DELIVERY TIME | 6464.145 | 4624.538 | 8508.333 | 4606.760 | 2541.316 | 154766.400 |
| MAX DELIVERY TIME | 155417.000 | 152893.000 | 155033.000 | 144219.000 | 4718.000 | 156693.000 |
| MIN DELIVERY TIME | 2400.000 | 2810.000 | 2406.000 | 2502.000 | 2403.000 | 154400.000 |
| STD DEV DELIVERY TIME | 19969.073 | 15823.597 | 23503.999 | 16290.853 | 316.486 | 761.249 |

ETHERNET FOR SIX SERVERS AND 30 PCs

COLLISION LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | COLLISION |
|---|---|
| COLLISION EPISODES | 3 |
| COLLIDED TRANSFERS | 8 |
| DEFERRALS | 15 |
| AVG DEFERRAL DELAY | 64571.787 |
| MAX DEFERRAL DELAY | 154086.400 |
| STD DEV DEFERRAL DELAY | 61746.608 |
| AVG DEFERRAL QUEUE | .032 |
| MAX QUEUE SIZE | 2.000 |
| STD DEV QUEUE SIZE | .220 |
| MULTIPLE COLLISIONS | 1 |
| AVG MULT COLLISIONS | 4.000 |
| MAX MULT COLLISIONS | 4 |
| SUCCESSFUL TRANSFERS | 208 |
| AVG USAGE TIME | 12434.380 |
| MAX USAGE TIME | 154400.000 |
| STD DEV USAGE TIME | 36686.784 |
| PER CENT OF TIME BUSY | 8.621 |

ETHERNET FOR SIX SERVERS AND 30 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 62 | 62 | 27 | 27 | 17 | 13 |
| AVG DELIVERY TIME | 6837.677 | 5577.210 | 5130.148 | 2502.000 | 24795.353 | 166039.846 |
| MAX DELIVERY TIME | 131090.000 | 158139.000 | 14264.000 | 2502.000 | 304141.000 | 303695.000 |
| MIN DELIVERY TIME | 2401.000 | 2810.000 | 2412.000 | 2502.000 | 2402.000 | 154400.000 |
| STD DEV DELIVERY TIME | 18865.552 | 19509.863 | 3487.968 | 0. | 72066.550 | 39741.251 |

[illegible] SIMLAN II RELEASE 1.01 02/1[illegible]/199[illegible] 10:52:50 PAGE 1

ETHERNET FOR SIX SERVERS AND 60 PCs

COLLISION LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | COLLISION |
|---|---|
| COLLISION EPISODES | 7 |
| COLLIDED TRANSFERS | 23 |
| DEFERRALS | 38 |
| AVG DEFERRAL DELAY | 41960.417 |
| MAX DEFERRAL DELAY | 149099.162 |
| STD DEV DEFERRAL DELAY | 53637.528 |
| AVG DEFERRAL QUEUE | .053 |
| MAX QUEUE SIZE | 4.000 |
| STD DEV QUEUE SIZE | .318 |
| MULTIPLE COLLISIONS | 4 |
| AVG MULT COLLISIONS | 4.250 |
| MAX MULT COLLISIONS | 5 |
| SUCCESSFUL TRANSFERS | 343 |
| AVG USAGE TIME | 11318.375 |
| MAX USAGE TIME | 154400.000 |
| STD DEV USAGE TIME | 34673.441 |
| PER CENT OF TIME BUSY | 12.941 |

ETHERNET FOR SIX SERVERS AND 60 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 92 | 91 | 50 | 50 | 41 | 19 |
| AVG DELIVERY TIME | 5200.804 | 7361.231 | 12464.960 | 2762.340 | 15565.732 | 154400.000 |
| MAX DELIVERY TIME | 127994.000 | 147353.000 | 136743.000 | 8010.000 | 151551.000 | 154400.000 |
| MIN DELIVERY TIME | 2402.000 | 2810.000 | 2410.000 | 2502.000 | 2404.000 | 154400.000 |
| STD DEV DELIVERY TIME | 14724.276 | 24604.564 | 27871.870 | 913.501 | 36831.944 | 0. |

CACI SIMLAN II RELEASE 1.01 12/10/1990 21:05:00 PAGE 1

ETHERNET FOR SIX SERVERS AND 90 PCs

COLLISION LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | COLLISION |
|---|---|
| COLLISION EPISODES | 51 |
| COLLIDED TRANSFERS | 171 |
| DEFERRALS | 148 |
| AVG DEFERRAL DELAY | 36463.087 |
| MAX DEFERRAL DELAY | 154348.800 |
| STD DEV DEFERRAL DELAY | 55531.855 |
| AVG DEFERRAL QUEUE | .180 |
| MAX QUEUE SIZE | 6.000 |
| STD DEV QUEUE SIZE | .743 |
| MULTIPLE COLLISIONS | 33 |
| AVG MULT COLLISIONS | 4.091 |
| MAX MULT COLLISIONS | 8 |
| SUCCESSFUL TRANSFERS | 573 |
| AVG USAGE TIME | 8108.206 |
| MAX USAGE TIME | 154400.000 |
| STD DEV USAGE TIME | 27843.024 |
| PER CENT OF TIME BUSY | 15.488 |

CACI SIMLAN II RELEASE 1.01 02/18/1990 21:05:00 PAGE 5

ETHERNET FOR SIX SERVERS AND 90 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 173 | 173 | 75 | 75 | 57 | 20 |
| AVG DELIVERY TIME | 16508.058 | 8952.636 | 16288.587 | 12509.600 | 8085.702 | 154749.350 |
| MAX DELIVERY TIME | 326078.000 | 142515.000 | 147491.000 | 155494.000 | 158908.000 | 158041.000 |
| MIN DELIVERY TIME | 2401.000 | 2810.000 | 2406.000 | 2502.000 | 2401.000 | 154400.000 |
| STD DEV DELIVERY TIME | 42429.481 | 27626.247 | 37265.818 | 36728.251 | 28709.959 | 910.392 |

CACI SIMLAN II RELEASE 1.01 02/21/1990 12:38:33 PAGE 1

STARLAN FOR THREE SERVERS AND 30 PCs

COLLISION LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | COLLISION |
|---|---|
| COLLISION EPISODES | 10 |
| COLLIDED TRANSFERS | 24 |
| DEFERRALS | 40 |
| AVG DEFERRAL DELAY | 84328.805 |
| MAX DEFERRAL DELAY | 466802.274 |
| STD DEV DEFERRAL DELAY | 134307.195 |
| AVG DEFERRAL QUEUE | .112 |
| MAX QUEUE SIZE | 4.000 |
| STD DEV QUEUE SIZE | .442 |
| MULTIPLE COLLISIONS | 3 |
| AVG MULT COLLISIONS | 3.333 |
| MAX MULT COLLISIONS | 4 |
| SUCCESSFUL TRANSFERS | 234 |
| AVG USAGE TIME | 26788.858 |
| MAX USAGE TIME | 521976.000 |
| STD DEV USAGE TIME | 106567.106 |
| PER CENT OF TIME BUSY | 18.21 |

STARLAN FOR THREE SERVERS AND 30 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 62 | 62 | 27 | 27 | 17 | 9 |
| AVG DELIVERY TIME | 29180.839 | 4358.387 | 54493.667 | 1411.333 | 33822.294 | 521976.000 |
| MAX DELIVERY TIME | 435447.000 | 6212.000 | 473898.000 | 5450.000 | 185017.000 | 521976.000 |
| MIN DELIVERY TIME | 243.000 | 4328.000 | 347.000 | 1256.000 | 242.000 | 521976.000 |
| STD DEV DELIVERY TIME | 87634.480 | 237.331 | 115019.163 | 792.048 | 62535.860 | 0. |

```
  SIMLAN II  RELEASE 1.      02/22 1988     01:45:55                                        PAGE  1

                                            STARLAN FOR THREE SERVERS AND 60 PCs

                                            COLLISION LAN UTILIZATION STATISTICS

                                              FROM   0.   TO   30. SECONDS

                                            (ALL TIMES REPORTED IN MICROSECONDS)

LAN NAME                 COLLISION


COLLISION EPISODES           27

COLLIDED TRANSFERS           78

DEFERRALS                    98
AVG DEFERRAL DELAY        94656.048
MAX DEFERRAL DELAY       501125.233
STD DEV DEFERRAL DELAY   154340.568

AVG DEFERRAL QUEUE             .309
MAX QUEUE SIZE                6.000
STD DEV QUEUE SIZE             .930

MULTIPLE COLLISIONS          15
AVG MULT COLLISIONS           3.600
MAX MULT COLLISIONS           6

SUCCESSFUL TRANSFERS        330
AVG USAGE TIME            17826.309
MAX USAGE TIME           521976.000
STD DEV USAGE TIME        84590.544

PER CENT OF TIME BUSY        19.612
```

STARLAN FOR THREE SERVERS AND 50 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO [illegible]. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 90 | 90 | 50 | 50 | 41 | 9 |
| AVG DELIVERY TIME | 43895.033 | 10314.278 | 40208.120 | 1723.260 | 78825.195 | 521976.000 |
| MAX DELIVERY TIME | 490671.000 | 510562.000 | 328713.000 | 15485.000 | 525971.000 | 521976.000 |
| MIN DELIVERY TIME | 256.000 | 4328.000 | 327.000 | 1256.000 | 276.000 | 521976.0[illegible] |
| STD DEV DELIVERY TIME | 119685.127 | 52077.658 | 88556.645 | 2295.834 | 152679.908 | 0. |

SIMLAN II RELEASE 1.0, 02/19/19[illegible] 10:06:11 PAGE 1

STARLAN FOR SIX SERVERS AND 30 PCs

COLLISION LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | COLLISION |
|---|---|
| COLLISION EPISODES | 8 |
| COLLIDED TRANSFERS | 16 |
| DEFERRALS | 36 |
| AVG DEFERRAL DELAY | 133661.365 |
| MAX DEFERRAL DELAY | 520656.000 |
| STD DEV DEFERRAL DELAY | 172582.668 |
| AVG DEFERRAL QUEUE | .160 |
| MAX QUEUE SIZE | 2.000 |
| STD DEV QUEUE SIZE | .425 |
| MULTIPLE COLLISIONS | 0 |
| AVG MULT COLLISIONS | 0. |
| MAX MULT COLLISIONS | 0 |
| SUCCESSFUL TRANSFERS | 208 |
| AVG USAGE TIME | 36363.534 |
| MAX USAGE TIME | 521976.000 |
| STD DEV USAGE TIME | 125539.598 |
| PER CENT OF TIME BUSY | 25.213 |

[illegible] II RELEASE [illegible] [illegible] 10106111

STARLAN FOR SIX SERVERS AND 30 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 62 | 62 | 27 | 27 | 17 | 13 |
| AVG DELIVERY TIME | 36109.210 | 4606.726 | 39051.963 | 1256.000 | 86318.647 | 562033.846 |
| MAX DELIVERY TIME | 510975.000 | 18674.000 | 348339.000 | 1256.000 | 440109.000 | 1042728.000 |
| MIN DELIVERY TIME | 243.000 | 4328.000 | 347.000 | 1256.000 | 255.000 | 521976.000 |
| STD DEV DELIVERY TIME | 101926.895 | 1838.676 | 83137.008 | 0. | 154502.794 | 138764.456 |

STARLAN FOR SIX SERVERS AND 60 PCs

COLLISION LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | COLLISION |
|---|---|
| COLLISION EPISODES | 47 |
| COLLIDED TRANSFERS | 135 |
| DEFERRALS | 162 |
| AVG DEFERRAL DELAY | 94347.951 |
| MAX DEFERRAL DELAY | 490183.915 |
| STD DEV DEFERRAL DELAY | 152638.724 |
| AVG DEFERRAL QUEUE | .509 |
| MAX QUEUE SIZE | 7.000 |
| STD DEV QUEUE SIZE | 1.132 |
| MULTIPLE COLLISIONS | 24 |
| AVG MULT COLLISIONS | 3.708 |
| MAX MULT COLLISIONS | 7 |
| SUCCESSFUL TRANSFERS | 338 |
| AVG USAGE TIME | 29476.704 |
| MAX USAGE TIME | 521976.000 |
| STD DEV USAGE TIME | 113426.546 |
| PER CENT OF TIME BUSY | 33.215 |

STARLAN FOR SIX SERVERS AND 60 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 90 | 90 | 50 | 50 | 41 | 17 |
| AVG DELIVERY TIME | 94155.044 | 5031.711 | 87659.600 | 1543.020 | 78694.854 | 521976.000 |
| MAX DELIVERY TIME | 503742.000 | 35265.000 | 501624.000 | 11958.000 | 509379.000 | 521976.000 |
| MIN DELIVERY TIME | 266.000 | 4328.000 | 327.000 | 1256.000 | 289.000 | 521976.000 |
| STD DEV DELIVERY TIME | 160287.560 | 3734.011 | 136761.852 | 1509.253 | 150929.907 | 0. |

STARLAN FOR SIX SERVERS AND 90 PCs

COLLISION LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | COLLISION |
|---|---|
| COLLISION EPISODES | 123 |
| COLLIDED TRANSFERS | 493 |
| DEFERRALS | 490 |
| AVG DEFERRAL DELAY | 95193.383 |
| MAX DEFERRAL DELAY | 521950.959 |
| STD DEV DEFERRAL DELAY | 171544.508 |
| AVG DEFERRAL QUEUE | 1.555 |
| MAX QUEUE SIZE | 16.000 |
| STD DEV QUEUE SIZE | 3.012 |
| MULTIPLE COLLISIONS | 70 |
| AVG MULT COLLISIONS | 5.529 |
| MAX MULT COLLISIONS | 16 |
| SUCCESSFUL TRANSFERS | 561 |
| AVG USAGE TIME | 19940.253 |
| MAX USAGE TIME | 521976.000 |
| STD DEV USAGE TIME | 91511.639 |
| PER CENT OF TIME BUSY | 37.301 |

CACI SIMLAN II RELEASE 1.01 02/19/1990 07:15:33 PAGE 5

STARLAN FOR SIX SERVERS AND 90 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST 1 | SEND RESPONSE TO PC 1 | SERVER REQUEST 2 | SEND RESPONSE TO PC 2 | SERVER REQUEST 3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 168 | 168 | 75 | 75 | 57 | 18 |
| AVG DELIVERY TIME | 133087.262 | 48672.661 | 121827.827 | 49128.907 | 127698.474 | 544581.944 |
| MAX DELIVERY TIME | 1168799.000 | 1094889.000 | 809344.000 | 798741.000 | 667231.000 | 893862.000 |
| MIN DELIVERY TIME | 237.000 | 4328.000 | 288.000 | 1256.000 | 261.000 | 521976.000 |
| STD DEV DELIVERY TIME | 149857.496 | 167433.518 | 199678.313 | 159699.991 | 197244.378 | 84933.083 |

TOKEN RING (4Mbps) FOR THREE SERVERS AND 30 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 205 |
| AVG REQUEST DELAY | 2269.595 |
| MAX REQUEST DELAY | 107250.075 |
| STD DEV REQUEST DELAY | 13267.284 |
| COMPLETED TRANSFERS | 205 |
| AVG USAGE TIME | 7972.000 |
| MAX USAGE TIME | 129600.000 |
| STD DEV USAGE TIME | 27587.124 |
| AVG QUEUE SIZE | .016 |
| MAX QUEUE SIZE | 2.000 |
| STD DEV QUEUE SIZE | .127 |
| TOKEN PASSES | 6794 |
| PER CENT OF TIME BUSY | 5.448 |

TOKEN RING (4Mbps) FOR THREE SERVERS AND 30 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 62 | 62 | 27 | 27 | 17 | 10 |
| AVG DELIVERY TIME | 6766.032 | 3423.065 | 4596.148 | 1056.000 | 1102.647 | 129645.700 |
| MAX DELIVERY TIME | 108054.000 | 100824.000 | 26671.000 | 1056.000 | 1470.000 | 130057.000 |
| MIN DELIVERY TIME | 803.000 | 1024.000 | 829.000 | 1056.000 | 806.000 | 129600.000 |
| STD DEV DELIVERY TIME | 20148.135 | 12470.925 | 5194.851 | 0. | 232.134 | 137.100 |

CACI SIMLAN II RELEASE 1.01 02/17/1990 22:16:35 PAGE 1

TOKEN RING (4Mbps) FOR THREE SERVERS AND 60 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 334 |
| AVG REQUEST DELAY | 1729.197 |
| MAX REQUEST DELAY | 108435.671 |
| STD DEV REQUEST DELAY | 11297.425 |
| COMPLETED TRANSFERS | 334 |
| AVG USAGE TIME | 5474.790 |
| MAX USAGE TIME | 129600.000 |
| STD DEV USAGE TIME | 21846.225 |
| AVG QUEUE SIZE | .019 |
| MAX QUEUE SIZE | 2.000 |
| STD DEV QUEUE SIZE | .156 |
| TOKEN PASSES | 20740 |
| PER CENT OF TIME BUSY | 6.095 |

TOKEN RING (4Mbps) FOR THREE SERVERS AND 60 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 92 | 91 | 50 | 50 | 41 | 10 |
| AVG DELIVERY TIME | 5300.261 | 1828.066 | 5096.680 | 1247.620 | 3388.780 | 129600.000 |
| MAX DELIVERY TIME | 109752.000 | 2194.000 | 80255.000 | 9091.000 | 92288.000 | 129600.000 |
| MIN DELIVERY TIME | 806.000 | 1824.000 | 824.000 | 1056.000 | 811.000 | 129600.000 |
| STD DEV DELIVERY TIME | 17372.401 | 38.573 | 11040.894 | 1141.187 | 14072.068 | 0. |

TOKEN RING (4Mbps) FOR THREE SERVERS AND 90 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 70. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 565 |
| AVG REQUEST DELAY | 2322.694 |
| MAX REQUEST DELAY | 133207.065 |
| STD DEV REQUEST DELAY | 14786.354 |
| COMPLETED TRANSFERS | 565 |
| AVG USAGE TIME | 3810.212 |
| MAX USAGE TIME | 129600.000 |
| STD DEV USAGE TIME | 16919.028 |
| AVG QUEUE SIZE | .044 |
| MAX QUEUE SIZE | 4.000 |
| STD DEV QUEUE SIZE | .274 |
| TOKEN PASSES | 51594 |
| PER CENT OF TIME BUSY | 7.176 |

TOKEN RING (4Mbps) FOR THREE SERVERS AND 90 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 175 | 173 | 75 | 75 | 57 | 10 |
| AVG DELIVERY TIME | 3599.891 | 3693.052 | 5363.213 | 1209.413 | 7144.965 | 129600.000 |
| MAX DELIVERY TIME | 127428.000 | 118487.000 | 97996.000 | 11864.000 | 134042.000 | 129600.000 |
| MIN DELIVERY TIME | 802.000 | 1824.000 | 814.000 | 1056.000 | 807.000 | 129600.000 |
| STD DEV DELIVERY TIME | 14566.379 | 14012.552 | 13422.064 | 1240.179 | 25851.272 | 0. |

TOKEN RING (4Mbps) FOR SIX SERVERS AND 30 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 208 |
| AVG REQUEST DELAY | 3570.050 |
| MAX REQUEST DELAY | 128418.750 |
| STD DEV REQUEST DELAY | 18200.139 |
| COMPLETED TRANSFERS | 208 |
| AVG USAGE TIME | 9726.250 |
| MAX USAGE TIME | 129600.000 |
| STD DEV USAGE TIME | 30989.696 |
| AVG QUEUE SIZE | .025 |
| MAX QUEUE SIZE | 2.000 |
| STD DEV QUEUE SIZE | .203 |
| TOKEN PASSES | 7435 |
| PER CENT OF TIME BUSY | 6.744 |

TOKEN RING (4Mbps) FOR SIX SERVERS AND 30 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 62 | 62 | 27 | 27 | 17 | 13 |
| AVG DELIVERY TIME | 6772.984 | 1824.000 | 7352.926 | 1056.000 | 11315.588 | 139478.385 |
| MAX DELIVERY TIME | 109065.000 | 1824.000 | 90805.000 | 1056.000 | 98336.000 | 258019.000 |
| MIN DELIVERY TIME | 803.000 | 1824.000 | 829.000 | 1056.000 | 806.000 | 129600.000 |
| STD DEV DELIVERY TIME | 22954.570 | 0. | 16693.331 | 0. | 25153.387 | 34219.728 |

[illegible] SIMLAN II RELEASE 1.01 02/17/1990 22:57:27 PAGE 1

TOKEN RING (4Mbps) FOR SIX SERVERS AND 60 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 343 |
| AVG REQUEST DELAY | 2312.904 |
| MAX REQUEST DELAY | 120575.453 |
| STD DEV REQUEST DELAY | 13731.974 |
| | |
| COMPLETED TRANSFERS | 343 |
| AVG USAGE TIME | 8731.719 |
| MAX USAGE TIME | 129600.000 |
| STD DEV USAGE TIME | 29298.366 |
| | |
| AVG QUEUE SIZE | .026 |
| MAX QUEUE SIZE | 3.000 |
| STD DEV QUEUE SIZE | .215 |
| | |
| TOKEN PASSES | 22220 |
| | |
| PER CENT OF TIME BUSY | 9.983 |

TOKEN RING (4Mbps) FOR SIX SERVERS AND 60 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 92 | 91 | 50 | 50 | 41 | 19 |
| AVG DELIVERY TIME | 4639.174 | 3081.890 | 10000.320 | 1216.700 | 1409.829 | 129600.000 |
| MAX DELIVERY TIME | 121687.000 | 114821.000 | 108346.000 | 9091.000 | 13834.000 | 129600.000 |
| MIN DELIVERY TIME | 806.000 | 1824.000 | 824.000 | 1056.000 | 811.000 | 129600.000 |
| STD DEV DELIVERY TIME | 16024.072 | 11779.202 | 23699.558 | 1124.900 | 1992.127 | 0. |

TOKEN RING (4Mbps) FOR SIX SERVERS AND 90 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 573 |
| AVG REQUEST DELAY | 5167.167 |
| MAX REQUEST DELAY | 133207.065 |
| STD DEV REQUEST DELAY | 22564.794 |
| COMPLETED TRANSFERS | 573 |
| AVG USAGE TIME | 6015.432 |
| MAX USAGE TIME | 129600.000 |
| STD DEV USAGE TIME | 23526.797 |
| AVG QUEUE SIZE | .099 |
| MAX QUEUE SIZE | 5.000 |
| STD DEV QUEUE SIZE | .448 |
| TOKEN PASSES | 52434 |
| PER CENT OF TIME BUSY | 11.489 |

TOKEN RING (4Mbps) FOR SIX SERVERS AND 90 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30 SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 173 | 173 | 75 | 75 | 57 | 20 |
| AVG DELIVERY TIME | 7602.942 | 7597.087 | 7798.347 | 1213.267 | 8947.351 | 129607.650 |
| MAX DELIVERY TIME | 127428.000 | 134357.000 | 97996.000 | 11864.000 | 134042.000 | 129753.000 |
| MIN DELIVERY TIME | 801.000 | 1824.000 | 814.000 | 1056.000 | 807.000 | 129600.000 |
| STD DEV DELIVERY TIME | 23574.016 | 26273.638 | 18443.717 | 1240.145 | 28076.386 | 33.346 |

TOKEN RING (16Mbps) FOR THREE SERVERS AND 30 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 206 |
| AVG REQUEST DELAY | 172.590 |
| MAX REQUEST DELAY | 23142.154 |
| STD DEV REQUEST DELAY | 1643.716 |
| COMPLETED TRANSFERS | 205 |
| AVG USAGE TIME | 5285.362 |
| MAX USAGE TIME | 38144.000 |
| STD DEV USAGE TIME | 7813.668 |
| AVG QUEUE SIZE | .001 |
| MAX QUEUE SIZE | 1.000 |
| STD DEV QUEUE SIZE | .034 |
| TOKEN PASSES | 6887 |
| PER CENT OF TIME BUSY | 3.629 |

TOKEN RING (16Mbps) FOR THREE SERVERS AND 30 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME: | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 62 | 62 | 27 | 27 | 17 | 11 |
| AVG DELIVERY TIME | 3741.952 | 3518.484 | 4010.889 | 3263.000 | 3423.647 | 38144.000 |
| MAX DELIVERY TIME | 26360.000 | 5614.000 | 6092.000 | 3263.000 | 5778.000 | 38144.000 |
| MIN DELIVERY TIME | 3201.000 | 3454.000 | 3207.000 | 3263.000 | 3201.000 | 38144.000 |
| STD DEV DELIVERY TIME | 2930.466 | 354.374 | 820.793 | 0. | 591.376 | 0. |

TOKEN RING (16Mbps) FOR THREE SERVERS AND 60 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 3[illegible] SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 335 |
| AVG REQUEST DELAY | 74.277 |
| MAX REQUEST DELAY | 4256.092 |
| STD DEV REQUEST DELAY | 429.632 |
| COMPLETED TRANSFERS | 335 |
| AVG USAGE TIME | 4549.798 |
| MAX USAGE TIME | 38144.000 |
| STD DEV USAGE TIME | 6198.532 |
| AVG QUEUE SIZE | .001 |
| MAX QUEUE SIZE | 1.000 |
| STD DEV QUEUE SIZE | .029 |
| TOKEN PASSES | 20998 |
| PER CENT OF TIME BUSY | 5.681 |

TOKEN RING (16Mbps) FOR THREE SERVERS AND 60 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO [illegible] |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SER[illegible] |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC [illegible] |
| NUMBER SENT | 92 | 91 | 50 | 50 | 41 | 11 |
| AVG DELIVERY TIME | 3337.054 | 3514.385 | 3987.840 | 3333.120 | 3331.585 | 38144.000 |
| MAX DELIVERY TIME | 6275.000 | 7710.000 | 6452.000 | 6344.000 | 5033.000 | 38144.[illegible] |
| MIN DELIVERY TIME | 3201.000 | 3454.000 | 3206.000 | 3263.000 | 3203.000 | 38144.[illegible] |
| STD DEV DELIVERY TIME | 462.513 | 453.046 | 769.471 | 434.220 | 320.698 | [illegible] |

TOKEN RING (16MBPS) FOR THREE SERVERS AND [illegible] PCS

TOKEN LAN UTILIZATION STATISTICS

FROM [illegible] TO [illegible] SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 564 |
| AVG REQUEST DELAY | 668.968 |
| MAX REQUEST DELAY | 39203.551 |
| STD DEV REQUEST DELAY | 3887.437 |
| COMPLETED TRANSFERS | 564 |
| AVG USAGE TIME | 4062.890 |
| MAX USAGE TIME | 38144.000 |
| STD DEV USAGE TIME | 4814.083 |
| AVG QUEUE SIZE | .013 |
| MAX QUEUE SIZE | 2.000 |
| STD DEV QUEUE SIZE | .134 |
| TOKEN PASSES | 50522 |
| PER CENT OF TIME BUSY | 7.638 |

CACI SIMLAN II RELEASE 1.0 [illegible] 20:28:15 PAGE [illegible]

TOKEN RING (16Mbps) FOR THREE SERVERS AND 90 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 173 | 173 | 75 | 75 | 57 | 11 |
| AVG DELIVERY TIME | 4120.618 | 3962.653 | 4443.013 | 3736.480 | 4158.860 | 38165.545 |
| MAX DELIVERY TIME | 40494.000 | 38507.000 | 42407.000 | 31291.000 | 27587.000 | 38381.000 |
| MIN DELIVERY TIME | 3200.000 | 3454.000 | 3211.000 | 3263.000 | 3202.000 | 38144.000 |
| STD DEV DELIVERY TIME | 4305.052 | 3366.595 | 4635.304 | 3247.973 | 4009.077 | 68.133 |

ACI SIMLAN II RELEASE 1.01 02/12/1990 11:47:54 PAGE

TOKEN RING (16Mbps) FOR SIX SERVERS AND 30 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 208 |
| AVG REQUEST DELAY | 278.307 |
| MAX REQUEST DELAY | 35874.964 |
| STD DEV REQUEST DELAY | 2629.222 |
| COMPLETED TRANSFERS | 208 |
| AVG USAGE TIME | 5601.310 |
| MAX USAGE TIME | 38144.000 |
| STD DEV USAGE TIME | 8411.193 |
| AVG QUEUE SIZE | .002 |
| MAX QUEUE SIZE | 1.000 |
| STD DEV QUEUE SIZE | .044 |
| TOKEN PASSES | 7596 |
| PER CENT OF TIME BUSY | 3.884 |

TOKEN RING (16Mbps) FOR SIX SERVERS AND 30 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 62 | 62 | 27 | 27 | 17 | 13 |
| AVG DELIVERY TIME | 3520.194 | 4100.468 | 4010.889 | 3263.000 | 3423.647 | 38144.000 |
| MAX DELIVERY TIME | 15458.000 | 39329.000 | 6092.000 | 3263.000 | 5778.000 | 38144.000 |
| MIN DELIVERY TIME | 3201.000 | 3454.000 | 3207.000 | 3263.000 | 3201.000 | 38144.000 |
| STD DEV DELIVERY TIME | 1557.111 | 4524.470 | 820.793 | 0. | 591.376 | 0. |

TOKEN RING (16Mbps) FOR SIX SERVERS AND 60 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 344 |
| AVG REQUEST DELAY | 763.850 |
| MAX REQUEST DELAY | 40376.681 |
| STD DEV REQUEST DELAY | 4568.426 |
| COMPLETED TRANSFERS | 344 |
| AVG USAGE TIME | 5428.716 |
| MAX USAGE TIME | 38144.000 |
| STD DEV USAGE TIME | 8134.533 |
| AVG QUEUE SIZE | .009 |
| MAX QUEUE SIZE | 3.000 |
| STD DEV QUEUE SIZE | .109 |
| TOKEN PASSES | 22378 |
| PER CENT OF TIME BUSY | 6.225 |

TOKEN RING (16Mbps) FOR SIX SERVERS AND 60 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 92 | 91 | 50 | 50 | 41 | 20 |
| AVG DELIVERY TIME | 3894.391 | 4750.187 | 3987.840 | 4093.900 | 4212.293 | 38144.000 |
| MAX DELIVERY TIME | 43629.000 | 32764.000 | 6452.000 | 41302.000 | 41133.000 | 38144.000 |
| MIN DELIVERY TIME | 3201.000 | 3454.000 | 3206.000 | 3263.000 | 3203.000 | 38144.000 |
| STD DEV DELIVERY TIME | 4336.903 | 5299.492 | 769.471 | 5333.140 | 5840.285 | [illegible] |

CACI SIMLAN II RELEASE [illegible] [illegible] 11:51:07 PAGE 1

TOKEN RING (16Mbps) FOR SIX SERVERS AND 90 PCs

TOKEN LAN UTILIZATION STATISTICS

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| LAN NAME | TOKEN RING |
|---|---|
| LAN REQUESTS GRANTED | 575 |
| AVG REQUEST DELAY | 850.525 |
| MAX REQUEST DELAY | 39203.551 |
| STD DEV REQUEST DELAY | 4570.274 |
| COMPLETED TRANSFERS | 575 |
| AVG USAGE TIME | 4714.876 |
| MAX USAGE TIME | 38144.000 |
| STD DEV USAGE TIME | 6672.883 |
| AVG QUEUE SIZE | .016 |
| MAX QUEUE SIZE | 2.000 |
| STD DEV QUEUE SIZE | .153 |
| TOKEN PASSES | 52915 |
| PER CENT OF TIME BUSY | 9.037 |

TOKEN RING (16Mbps) FOR SIX SERVERS AND 90 PCs

MESSAGE DELIVERY REPORT

FROM 0. TO 30. SECONDS

(ALL TIMES REPORTED IN MICROSECONDS)

| MESSAGE NAME | SERVER REQUEST-1 | SEND RESPONSE TO PC 1 | SERVER REQUEST-2 | SEND RESPONSE TO PC 2 | SERVER REQUEST-3 | SEND RESPONSE TO PC 3 |
|---|---|---|---|---|---|---|
| SOURCE STATION | PC 1 | SERVER 1 | PC 2 | SERVER 2 | PC 3 | SERVER 3 |
| DESTINATION STATION | SERVER 1 | PC 1 | SERVER 2 | PC 2 | SERVER 3 | PC 3 |
| NUMBER SENT | 173 | 173 | 75 | 75 | 57 | 22 |
| AVG DELIVERY TIME | 4315.017 | 4411.497 | 4443.013 | 3736.480 | 4167.158 | 38154.773 |
| MAX DELIVERY TIME | 40494.000 | 39547.000 | 42407.000 | 31291.000 | 27587.000 | 38381.000 |
| MIN DELIVERY TIME | 3200.000 | 3454.000 | 3211.000 | 3263.000 | 3202.000 | 38144.000 |
| STD DEV DELIVERY TIME | 4971.324 | 5023.771 | 4635.304 | 3247.973 | 4007.741 | 49.367 |

## INITIAL DISTRIBUTION LIST

No. of Copies

1. Defense Technical Information Center.... ..........................................2
   Cameron Station
   Alexandria, VA 22304-6145

2. Library, Code 0142 ................................................................ ..............2
   Naval Postgraduate School
   Monterey, CA 93943-5002

3. Prof. Dan C. Boger, Code AS/Bo.......................................................2
   Department of Administrative Sciences
   Naval Postgraduate School
   Monterey, CA 93943-5000

4. Professor Myung W. Suh, Code AS/Su...............................................1
   Department of Administrative Sciences
   Naval Postgraduate School
   Monterey, CA 93943-5000

5. Professor Gary K. Poock, Code OR/Pk................................................1
   Department of Operation Research
   Naval Postgraduate School
   Monterey, CA 93943-5000

6. Naval Academy Library..........................................................................3
   P. O. Box 8494 Tsoying
   Kaoshiung City, Taiwan,
   Republic of China

7. Yeh, Sheau-Ching.....................................................................................2
   5347 Golden West Avenue
   Temple City, CA 91780

8. Chih-Lun Chou .........................................................................................8
   4F. No. 46, Lane 10, DAH-REN St. JONG-HER City
   Taipei, Taiwan, Republic of China. 23540